Volume 13 SEPTEMBER 1929 Number 9

BULLETIN

of the

American Association *of* Petroleum Geologists

CONTENTS

Problem of Crooked Holes — *Frederic H. Lahee* — 1095

Control and Adjustment of Surveys with the Magnetometer or the Torsion Balance — *Donald C. Barton* — 1163

Geologic and Economic Notes on Venezuelan Oil Developments — *Edwin B. Hopkins and H. J. Wasson* — 1187

Geological Notes

- Graphic Solution of Strike and Dip from Two Angular Components — *H. W. Kitson* — 1211
- Correlatives of Mohawkian Sediments in Kansas — *G. Marshall Kay* — 1213
- Fisk, or Shields, Pool, Coleman County, Texas — *Robert H. Durward* — 1214
- State of São Paulo, Brazil — *Chester W. Washburne* — 1215

Discussion

- Origin of Porosity in Reef Limestone or Dolomite — *E. Russell Lloyd* — 1219

Research Notes

- Remarks on Recent Research Work on the Genesis of Petroleum — *W. A. J. M. van Waterschoot van der Gracht* — 1221
- Study of the Crooked Hole Problem — *F. H. Lahee* — 1227

Reviews and New Publications

- Recent Publications — 1229

The Association Round Table — 1231

Memorial

- Frank Parkes Latimer — *R. J. Riggs* — 1237
- Rudolf R. Pollok — *Walter Stalder* — 1237
- Harry H. Wilson — *William L. Clark* — 1238

At Home and Abroad — 1241

COPYRIGHT, 1929, BY THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

What You Should Know About Baker Cement Floating, Guiding, and Cementing Equipment

There are certain facts — they may properly be called Basic Facts — which everyone should know about Baker Cement Equipment. The name "Baker Cement Equipment" is generic, covering the complete line of Floating, Guiding, and Cementing Equipment in which Baker has substituted a special Baker-Formula concrete for the usual cast iron in the inner or removable parts. The absence of obstructive fragments of cast iron in the bottom of the hole permits taking a core when it is of vital importance.

FACT ONE — The Baker Organization saw the need for something to take the place of Cast Iron in this type of equipment. It then engineered, field-tested, and perfected such a line of equipment.

FACT TWO — Ordinary good concrete has a compressive strength of 2800 to 3700 pounds. The original Baker Formula concrete tested 4115 pounds. Laboratory tests and other means were used to improve this strength, and it was gradually brought up to 5534 pounds. Then a further improvement was made, and under date of July 26, 1929, our laboratory reports a compressive strength of 6002 pounds.

FACT THREE — The entire line of Baker Cement Equipment is covered by patents granted and patents pending.

FACT FOUR—Baker has been through the mill for two years. Baker Cement Equipment is absolutely trustworthy and makes good on the job.

Informative, illustrated literature on the entire line will be mailed on request.

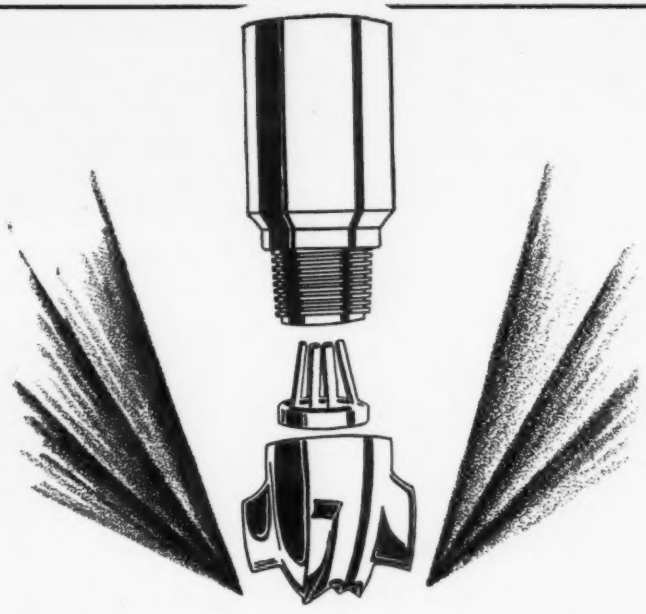
Export Sales Office
25 Broadway, New York City

Mid-Continent Branches
Tulsa, Oklahoma
Houston, Texas

BAKER
OIL TOOLS, INC.
(Formerly Baker Casing Shoe Co.)
Box L, HUNTINGTON PARK, CAL.

California Branches
Coalinga Taft Bakersfield Ventura

Mid-Continent Distributors
B & A SPECIALTY COMPANY
2301 Commerce St.,
Houston, Texas
220 E. Brady St.,
Tulsa, Okla.



THE expressed preference of most rotary drillers for the Elliott Core Drill is the result of intimate knowledge of a tool that invariably secures perfect cores at the lowest possible cost per foot of recovery.

Complete details of Elliott Core Drills will be furnished upon request.

ELLIOTT CORE DRILLING CO.
840 Subway Terminal Building
LOS ANGELES, CALIFORNIA

EXPORT OFFICE:
150 Broadway, New York

ELLIOTT CORE DRILLS

Distributed exclusively in the United States east of the Rocky Mountains, by

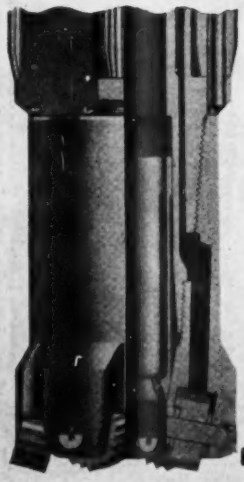
REED ROLLER BIT COMPANY

REED
ROTARY
DRILLING
TOOLS
SPEED-ECONOMY-DURABILITY

NOW

IT'S

REED + ELLIOTT

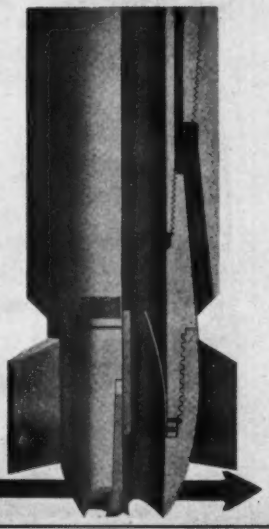


The Reed Roller Bit Company has acquired all of the stocks, machinery and personal properties of the Elliott Core Drilling Company in the United States, east of the Rocky Mountains.

It has also acquired all foreign sales rights on this tool.

This transaction was made with the sole object in view of giving operators the very highest quality soft formation coring tool as well as a hard formation core bit.

Reed Rock Core Bit heads and reamers and Reed-Elliott soft formation core bit heads will be made inter-changeable on Elliott barrels.



REED ROTARY DRILLING TOOLS

SPEED - ECONOMY - DURABILITY

Reed Rock Core Bit Complete

THIS interchangeability will effect a very material saving on the first cost of Reed Rock Core Bits to those who now own Elliott soft formation bits and will permit of equipping to core in any type formation with a minimum outlay for coring equipment.

Illustrated here is a Reed Rock Core Bit with standard core catcher and cut out showing how the Reed-Elliott head can be substituted on the same barrel equipment either with or without reamer.

The real economy in the use of The Reed Rock Core Bit has already won for this tool an enviable place with the drilling fraternity, due to the possibility of quick cutter change, the interchangeability of all cutters, pins and washers and the possibility of re-using a goodly portion of each set of cutters on more than one run. Individual parts of sets of cutters may be purchased as required.

Attention is called to the ample tong space provided on both types of heads to facilitate easy handling on the derrick floor.

A complete bulletin covering this combination tool is yours for the asking.

Reed-Elliott Core Bit Complete with Reamer

Reed-Elliott Core Bit Without Reamer

REED ROLLER BIT CO.

HOUSTON, TEXAS

Gulf Coast and Mid-Continent Distributors

Martin-Loomis Automatic Recording Weight Indicator

FAIRCHILD

AERIAL SURVEYS, INC.

(*Division of* FAIRCHILD AVIATION CORP., *New York*)

FAIRCHILD offers the Petroleum Geologist and associated engineering groups expert service in economically producing:

1 AERIAL PHOTOGRAPHIC RECONNAISSANCE STUDIES AND COMPLETE MAP ASSEMBLIES FOR:

The study of general or regional surface geology and drainage.

The examination of variations in surface topography through the stereoscopic study of properly indexed sets of overlapping photographic prints.

The economic location of pipe lines and other extensive development or construction.

2 OBLIQUE AERIAL PHOTOGRAPHIC VIEWS:

For detailed perspective record of small selected areas and operating properties or the general visualization of extended territory.

3 AIRPLANE TRANSPORTATION AND SPECIAL FLIGHTS USING:

Fairchild Cabin Monoplanes flown by experienced transport pilots particularly trained to aid the client in securing the best results from his observation, reconnaissance, or photographic assignment.

OUR SEVERAL BRANCH OFFICES AND COMPLETE LABORATORIES ASSURE YOU A CLOSE COÖPERATION AND ADEQUATE SERVICE.

FAIRCHILD AERIAL SURVEYS, INC.

270 W. 38th St., New York City

BRANCH OFFICES AT: 2102 N. Harwood St., Dallas, Tex. -:- 224 E. 11th St., Los Angeles, Calif. -:- McCormick Bldg., Chicago, Ill. -:- Metropolitan Bldg., Boston, Mass.

THE BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

F. H. LAHEE, *Third Vice-President in Charge of Editorial Work*
J. P. D. HULL, *Acting Editor*

REGIONAL ASSOCIATE EDITORS

Foreign:	W. B. HEROY, Room 1500, 45 Nassau Street, New York City
General:	K. C. HEALD, The Gulf Companies, Frick Building Annex, Pittsburgh, Pennsylvania
Appalachian:	GAIL F. MOULTON, Illinois State Geological Survey, Urbana, Illinois
North Mid-Continent:	FRANK C. GREENE, Shell Petroleum Corp., Box 1162, Tulsa, Okla.
South Mid-Continent:	R. E. RETTGER, Sun Oil Company, San Angelo, Texas
Gulf Coast:	DONALD C. BARTON, Petroleum Building, Houston, Texas
Louisiana-Arkansas:	W. C. SPOONER, Box 1195, Shreveport, Louisiana
Rocky Mountain:	R. CLARE COFFIN, 931 First National Bank Building, Denver, Colorado
Pacific Coast:	W. S. W. KEW, Standard Oil Company, 524 Standard Oil Building, Los Angeles, California

The Bulletin of the American Association of Petroleum Geologists is published by the Association on or about the 15th of each month. Editorial and publication office, 504 Tulsa Building, Tulsa, Oklahoma, Post Office Box 1852.

The subscription price to non-members of the Association is $15.00 per year (separate numbers $1.50) prepaid to addresses in the United States, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Dominican Republic, Canary Islands, El Salvador, Argentina, Bolivia, Brazil, Colombia, Chile, Costa Rica, Ecuador, Guatemala, Honduras, Nicaragua, Peru, Hayti, Uruguay, Paraguay, Hawaiian Islands, Philippine Islands, Guam, Samoan Islands, Balearic Islands, and Spain.

Postage is charged extra: For Canada, 40 cents on annual subscriptions (total $15.40), and for all other countries in the Postal Union, 70 cents on annual subscriptions (total $15.70).

British agent: Thomas Murby & Co., 1 Fleet Lane, Ludgate Circus, London, E. C. 4.

German agent: Max Weg, Königstrasse 3, Leipzig, Germany.

Claims for non-receipt of preceding numbers of the BULLETIN must be sent to the business manager within three months of the date of publication in order to be filled gratis.

Back numbers of the BULLETIN can be ordered from the business manager at the following prices: Vol. 2, $4.00; Vol. 3, $5.00; Vol. 4, numbers 2 and 3, each $3.00; Vols. 5 and 6, cloth bound, each $12.00; Vols. 7 and 8, cloth bound, each $11.50; separate numbers, each $2.00 except Vol. 5, No. 2, $3.50; Vols. 9, 10, 11, 12, cloth bound, each $17.00; separate numbers, each $1.50, except Vol. 9, numbers 1, 2, and 3, each $3.00, Vol. 10, numbers 3, 11, and 12, each $2.00, and Vol. 11, number 3, $2.00. Symposium, Theory of Continental Drift, 240 pp., 29 illus., $3.50. 10-Volume Index (1917-1926), $2.00. Structure of Typical American Oil Fields, Vol. 1, 510 pp., 194 illus., $5.00.

The BULLETIN furnishes thirty-five free reprints of major papers. Additional reprints and covers for all or part, are furnished at cost. **Orders for reprints** should accompany corrected galley proof.

Association Headquarters—504 Tulsa Building, East Fifth Street at Cincinnati Avenue, Tulsa, Oklahoma.

Communications about the Bulletin, manuscripts, editorial matters, subscriptions, special rates to public and university libraries, publications, membership, change of address, advertising, and other Association business should be addressed to

J. P. D. HULL, *Business Manager*
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
BOX 1852
TULSA, OKLAHOMA

Entered as second-class matter at the Post Office at Tulsa, Okla., under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

MID-WEST PRINTING CO., TULSA, OKLA., U. S. A.

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OFFICERS FOR THE YEAR ENDING MARCH, 1930

J. Y. SNYDER, *President*
Shreveport, Louisiana

R. S. McFARLAND *Past-President*
Tulsa, Oklahoma

FRED H. KAY, *First Vice-President*
New York, New York

A. R. DENISON, *Second Vice-President in Charge of Finances*
Fort Worth, Texas

FREDERIC H. LAHEE, *Third Vice-President in Charge of Editorial Work*
Dallas, Texas

DISTRICT REPRESENTATIVES

(Representatives' terms expire immediately after annual meetings of the years shown in parentheses.)

Abilene:
M. G. Cheney (1931), Coleman, Tex.
Amarillo:
C. Max Bauer (1930), Boulder, Colo.
Appalachian:
R. E. Somers (1931), Pittsburgh, Pa.
Ardmore—Oklahoma City:
S. H. Woods (1929), Ardmore, Okla.
Canada:
O. B. Hopkins (1929), Toronto, Can.
Capital:
H. D. Miser (1930), Washington, D. C.
Dallas:
Willis Storm (1930), Dallas, Tex.
Enid:
Glenn C. Clark (1930), Ponca City, Okla.
Fort Worth:
H. B. Fuqua (1929), Fort Worth, Tex.
Great Lakes:
A. C. Trowbridge (1931), Iowa City, Iowa.
Houston:
J. M. Vetter (1931), Houston, Tex.
Mexico:
S. A. Grogan (1931), Tampico, Mex.
New York:
H. J. Wasson (1931), New York, N. Y.
Pacific Coast:
C. R. McCollom (1930), Los Angeles, Calif.
N. L. Taliaferro (1929), Berkeley, Calif.
E. F. Davis (1931), Los Angeles, Calif.
Rocky Mountains:
H. A. Stewart (1930), Denver, Colo.
Charles M. Rath (1931), Denver, Colo.
San Angelo:
R. F. Imbt (1931), San Angelo, Tex.
San Antonio:
Chas. H. Row (1931), San Antonio, Tex.
Shreveport:
W. E. Hopper (1929), Shreveport, La.
South America:
J. B. Burnett (1929), Maracaibo, Venezuela, S. A.
Tulsa:
Sidney Powers (1930), Tulsa, Okla.
Robert J. Riggs (1929), Bartlesville, Okla.
A. W. Duston (1931), Tulsa, Okla.
Wichita:
Marvin Lee (1929), Wichita, Kan.
Wichita Falls:
C. W. Clark (1930), Wichita Falls, Tex.
Representative-at-large:
Donald C. Barton (1930), Houston, Tex.

PACIFIC SECTION

(Chartered, March, 1925)

EARL B. NOBLE, *President*, 514 Union Oil Building, Los Angeles, California
E. M. BUTTERWORTH, *Secretary-Treasurer*, 524 Standard Building, Los Angeles, California

Membership is restricted to members of the A.A.P.G. in good standing, residing in the Pacific Coast states. Dues of $2.00 per year are payable to the secretary-treasurer of the Pacific Coast Section. Members of the A.A.P.G. transferring to the Pacific Coast are cordially invited to become affiliated with the local section, and to communicate their change of address promptly to the secretary-treasurer of the Pacific Section.

SAN ANTONIO SECTION

(Chartered, April, 1929)

CHARLES H. ROW, *President*, Sun Oil Company, San Antonio, Texas
KENNETH DALE OWEN, *Secretary-Treasurer*, Southern Crude Oil Purchasing Company, San Antonio, Texas

Membership is limited to persons who are eligible to membership in the American Association of Petroleum Geologists. Annual dues: $2.50. Annual meeting: the last Friday in February of each year.

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

(Affiliated, March, 1928)

MARCUS A. HANNA, *President*, Houston, Texas
F. B. PLUMMER, *Secretary-Treasurer*, Bureau of Economic Geology, Austin, Texas

This is an affiliated society of the A.A.P.G. The Society issues a quarterly, the *Journal of Paleontology*, JOSEPH A. CUSHMAN, *Editor*, Sharon, Massachusetts. Membership application forms and back numbers of the *Journal* may be obtained from A.A.P.G. Headquarters, Box 1852, Tulsa, Oklahoma.

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Vol. 13 SEPTEMBER 1929 No. 9

CONTENTS

PROBLEM OF CROOKED HOLES 1095
By FREDERIC H. LAHEE

CONTROL AND ADJUSTMENT OF SURVEYS WITH THE MAGNETOMETER OR THE TORSION BALANCE 1163
By DONALD C. BARTON

GEOLOGIC AND ECONOMIC NOTES ON VENEZUELAN OIL DEVELOPMENTS 1187
By EDWIN B. HOPKINS AND H. J. WASSON

GEOLOGICAL NOTES

Graphic Solution of Strike and Dip from Two Angular Components, *H. W. Kitson* 1211
Correlatives of Mohawkian Sediments in Kansas, *G. Marshall Kay* 1213
Fisk, or Shields, Pool, Coleman County, Texas, *Robert H. Durward* 1214
State of São Paulo, Brazil, *Chester W. Washburne* 1215

DISCUSSION

Origin of Porosity in Reef Limestone, *E. Russell Lloyd* 1219

RESEARCH NOTES

Remarks on Recent Research Work on the Genesis of Petroleum, *W. A. J. M. van Waterschoot van der Gracht* 1221
Study of the Crooked Hole Problem, *F. H. Lahee* 1227

REVIEWS AND NEW PUBLICATIONS

Recent Publications 1229

THE ASSOCIATION ROUND TABLE

Honorary Member 1231
Membership Applications Approved for Publication 1231
Executive Committee at Dallas, August 17, 1929 1282
A. A. P. G. Insignia 1233
Preprints 1234
Program for New Orleans Meeting, March 20-22, 1930 1235

MEMORIAL

Frank Parkes Latimer, *R. J. Riggs* 1237
Rudolf R. Pollok, *Walter Stalder* 1237
Harry H. Wilson, *William L. Clark* 1238

AT HOME AND ABROAD

Current News and Personal Items of the Profession 1241

Articles Scheduled for Publication in the October *Bulletin*

Carbon Ratios and Oil Gravity in the Rocky Mountain Region of the United States

By C. E. DOBBIN

Temperature Gradient in Pechelbronn Oil-Bearing Region: Its Determination and Relation to Oil Reserves

By I. O. HAAS and C. R. HOFFMANN

Subsurface Structure of Some Unsymmetrical Anticlines in the Rocky Mountains

By J. G. BARTRAM and J. E. HUPP

Georgetown Formation of Central Texas and Its Northern Texas Equivalents

By ROBERT H. CUYLER

Structural Features of West Franklin Formation of Southwestern Indiana

By ROBERT R. SHROCK and CLYDE A. MALOTT

Undergraduate Preparation for the Geologist

By ELLIS W. SHULER

Unconformities in the Upper Cretaceous Series of Texas

By LLOYD W. STEPHENSON

Correlation of the Claiborne of East Texas with the Claiborne of Louisiana

By ALVA C. ELLISOR

Lower Claiborne of East Texas with Special Reference to Mt. Sylvan Dome and Salt Movements

By E. A. WENDLANDT and G. MOSES KNEBEL

Significance of Micro-Crystals of Carbonates in Bituminous Shales. A Preliminary Note

By RAPHAEL J. TAKAHASHI

Volume 13 Number 9

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

SEPTEMBER 1929

PROBLEM OF CROOKED HOLES[1]

FREDERIC H. LAHEE[2]
Dallas, Texas

ABSTRACT

In the oil industry, the problem of crooked holes is second in importance only to the problem of overproduction. For many years we have known that exploratory core holes in mining regions may be crooked. For several years attention has been given to this matter in California, where numerous cases of crooked holes are on record. But only last year was a serious study made of the problem in the Mid-Continent. After describing several examples of crooked diamond drill holes, ordinary rotary holes, and cable-tool holes, the writer discusses the effects, measurement, and causes of the deviation of holes from the vertical, and the remedies suggested.

That we should do all in our power to study this problem, for the purpose of learning how to drill holes essentially vertical, is emphasized by the enormous losses in time and money which have been directly or indirectly attributable to crooked holes.

ACKNOWLEDGMENTS

About five months ago 75 or 80 circular letters asking for data on crooked holes were sent to geologists and engineers. Nearly all replied. We wish to state here, that without this willing coöperation, the present paper would have been impossible. We are most grateful for all the assistance rendered and especially want to thank the following persons for their kind assistance and suggestions: Morris C. Allen, Alexander Anderson, G. E. Dorsey, J. E. Elliott, G. C. Gester, H. B. Goodrich, E. J. Gorman, H. B. Hill, H. H. Hill, P. S. Justice, A. A. Langworthy, R. S. McFarland, Desaix B. Myers, R. Van A. Mills, Wilson K. Page, Sidney

[1]Read before the Association at the Fort Worth meeting, March 23, 1929. Manuscript received by the editor, March 30, 1929.

[2]Chief geologist, Sun Oil Company.

Powers, John A. Ritter, D. R. Snow, C. Beeby Thompson, W. W. Warner, and Luther White.

THE PROBLEM AND THE PETROLEUM INDUSTRY

There is no industry more intricately woven into our modern civilization, no industry which has witnessed a more extraordinary development in its technique, than the petroleum industry. Each year new processes are discovered, new methods are evolved, and new inventions are made. Because of these multifarious contacts with our living conditions, and because of this rapid evolution in scientific operation, we are confronted, in this industry, by many problems, large and small, local and regional, some so far-reaching that they are truly fundamental in their importance. But let no one imagine for a moment that this multiplicity of problems spells disaster or suggests even a hint of discouragement. Rather do they mark the industry as young and full of vitality. They are the tokens of progress. They are a real inspiration to all of us to think and work.

To-day the problem of overproduction is of first importance. Its solution should claim the earnest study and unselfish coöperation of all producers alike, whether major companies or individuals, for the ambitions of each and all should be reasonable net profits permitting reasonable expansion in a reasonable time.

Only second in importance to the problem of overproduction is the problem of crooked holes. To some this may sound like a gross exaggeration, or like a fall from the sublime to the ridiculous; but when we consider how many holes have been drilled off the vertical, and, where such is the case, what large sums of money have been lost in drilling operations, in producing operations, in false or inadequate geological interpretations, and in erroneous technical deductions based on assumed well spacing—when we consider the almost endless ramifications of these opportunities for loss, we can better appreciate the significance of this problem.

Probably few holes have been drilled absolutely vertical. The real wonder is that so many are comparatively straight. But we are not so much concerned now with the holes of yesterday, which were relatively shallow, and which were no doubt for the most part sufficiently straight for all practical purposes. We are concerned with the holes of to-day and to-morrow, holes which are being carried to depths ranging from 5,000 feet to 8,000 feet and which will soon be reaching down nearly two miles into the earth. These are the holes which we *must* drill vertical,

for otherwise our plans and aspirations, based on promising surface or shallow subsurface evidence, will be worth nothing. If 3,000-foot and 4,000-foot holes can wander off horizontally scores or even hundreds of feet from where they started, what is not possible in an 8,000-foot hole? It is for this reason, therefore, that we say that the crooked hole problem, the problem of how to survey the courses of holes and how to drill them straight, is the second most important problem before the industry to-day.

EXAMPLES OF CROOKED HOLES

Definitions.—The term "crooked hole," as used in this paper, refers to any hole which deviates from its predetermined course. In most cases, since the original intention was to drill vertically downward into the earth, crooked holes are those deviating in any manner from a vertical line, but some diamond drill holes have been started at an angle oblique to the vertical and have subsequently turned from their first direction.

Classification of holes.—Before discussing the causes and effects of the deviation of holes from their intended course, we shall present a few of the examples which help to emphasize the urgency of the problem. Many of these examples are well known to some of you, but probably few of you are acquainted with all. This is our excuse for hazarding a repetition.

For obvious reasons, we classify these cases as (1) diamond drill holes, cut in hard rock strata by a rotating diamond bit at the lower end of a revolving string of pipe; (2) ordinary rotary holes, drilled for oil or gas by means of a fishtail bit, disc bit, cone bit, or other similar bit, rotated at the lower end of a revolving string of pipe; and (3) cable-tool holes, drilled by the repeated impact of a heavy bit suspended at the end of a cable.[1]

Nature of diagrams of crooked holes.—In studying the figures, one should discriminate between perpendicular projections of the mapped course of the hole onto vertical planes fixed in azimuth, on the one hand, and diagrammatic sketches of the recorded angles, all rotated into the same vertical plane, on the other hand. Most of the figures used are of the latter class, for they show merely the angle of deviation from the vertical, without taking account of the direction, the angle being the only quantity which is ordinarily recorded in our present methods of well surveying. Where the *direction* of deviation is obtained, as by

[1]Reference is not made here to the various modifications of some of these methods of drilling.

Anderson's method (see p. 1148), the former type of diagram is employed. Compare, for instance, Figures 8 and 9 with Figure 7.

Construction of charts showing vertical deviation.—A word may be said about the construction of charts of the second class, previously mentioned. Where angles of deviation are determined in a hole, by employing simple apparatus like the acid bottle (see p. 1145), these recorded angles refer to very short sections of the hole. Thus, angles may be read at depths of 500 feet, 1,000 feet, and so on at 500-foot intervals. Using these angles, the course of the hole can be plotted in a vertical plane in three ways: (1) the angle can be plotted from the point where it was observed downward to the next point of observation (*A*, Fig. 1); or (2) it can be plotted upward to the last point of observation; or (3) it can be plotted through the point at which it was measured both upward half way to the next higher point of observation and downward half way to the next lower similar point (*B*, Fig. 1). As can readily be seen, the first and second methods are unreasonable, for we must suppose that ordinarily there has been a gradual increase or decrease in the angle upward or downward in the hole to the point of measurement. The third method is the best for it obtains better averages; but its results can be secured more easily by simply taking the average angle between each two stations, and plotting this average between these two stations (see *C*, Fig. 1). Compare the vertical and horizontal displacements of the observation point at a measured depth of 3,416 feet in each of the three diagrams in Figure 1.

Diamond drill holes.—In the mining industry, the diamond drill has been used for exploratory work for more than fifty years. Mention was made of the effect of inclined strata in deflecting a bore hole as early as 1872;[1] but the real importance of the crooked hole problem, in diamond drilling, seems to have received most comment, and efforts to solve this problem seem to have met with most success, during the first fifteen years of the present century. In that fifteen years much was accomplished in the way of measuring the crookedness of holes, straightening holes which deviated far from the vertical, and improving upon the methods of drilling so that the holes were more nearly plumb in the first place.

It is very interesting, as a commentary on the possibly too great self-sufficiency of the oil industry, that we are now hardly more than entering a period of repetition of the discussions and studies which occupied the attention of the mining industry nearly a quarter of a century

[1]Eckley B. Coxe, "A New Method of Sinking Shafts," *Trans., Amer. Inst. Min. Eng.*, Vol. 1 (1872), pp. 261-76.

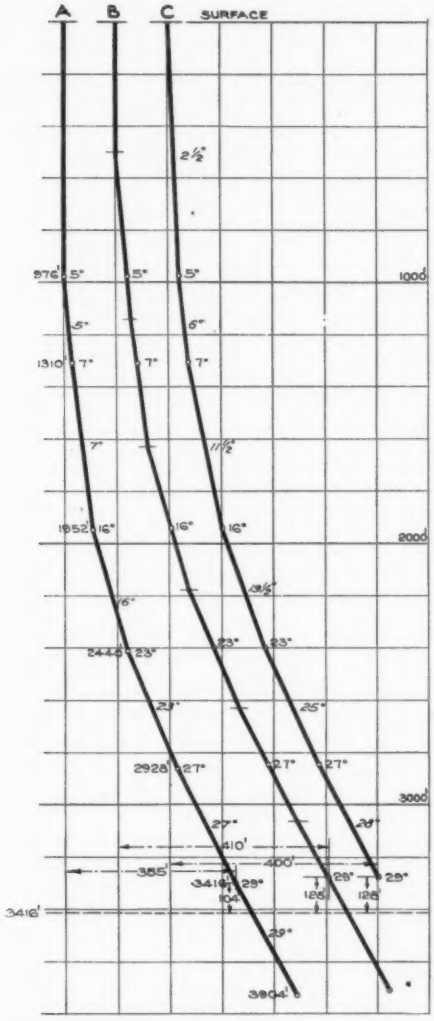


FIG. 1.—Methods of plotting deviation of holes where readings are made at intervals and angular deviation is assumed to be all in same vertical plane. Depth figures shown in this and following illustrations indicate feet.

ago. It behooves us to read with care the writings and suggestions of those mining men who deliberated on this matter several years ago.

In 1907, Joseph Kitchin[1] presented a paper summarizing the results obtained in surveying 40 diamond holes drilled on the Rand in South Africa. Figures for 22 holes were tabulated. The total average depth, or measured length, of these 22 holes, was 3,370 feet, whereas the average vertical depth of their deepest surveyed points was 3,015 feet. Thus, there was an average excess of 355 feet drilled in every hole, or a total excess of 8,810 feet in the 22 holes. For these 22 borings, the average displacement of the bottom of the hole, measured horizontally from the mouth, was 1,165 feet. The highest recorded angle of deviation from the vertical was 66° at 4,400 feet, in the Turf Mines No. 2.[2]

Three interesting cases of shallow crooked diamond drill holes are cited by E. E. White.[3] One hole, which started vertical, had deviated to 39° from a plumb line at 800 feet. Another, which was started at an angle in a direction N. 54° W. had turned to N. 64° E. at the bottom. A third hole which started vertical, had migrated a horizontal distance of 377 feet at a total depth of only 1,290 feet.

Figure 2, *A*, shows a vertical projection of the course of a hole (1)[4] described by Morris C. Allen of the Sullivan Machinery Company.[5]

This hole, which was started at an angle of about 34° from the vertical, acquired a lower and lower inclination until, at a measured depth of 1,400 feet, it was 72° from the vertical, or only 18° from the horizontal. We mention this example because it so clearly illustrates this rather common tendency, observed in holes drilled under too much pressure, to deviate more and more toward a horizontal position.

In a most instructive paper, published in 1913, Hoffman[6] described and figured two deep diamond holes, drilled in South Africa. These were, first, a hole(2) drilled by the Lace Proprietary Mines on the farm Vlak-

[1]Joseph Kitchin, "The Deviation of Rand Bore-Holes from the Vertical," *Trans. Inst. Min. and Met.* (London, 1907), Vol. 17, pp. 87-136.

[2]Joseph Kitchin, *op. cit.*, p. 90.

[3]E. E. White, "Surveying and Sampling Diamond Drill Holes," *Trans. Amer. Inst. Min. Eng.*, Vol. 44 (1912), pp. 69-90.

[4]Throughout this paper examples of holes are numbered consecutively so that they may be designated without referring to their farm or company names.

[5]Personal communication.

[6]John I. Hoffman, "Recent Practice in Diamond Drilling and Borehole Surveying," *Bull. Inst. Min. and Met.* (London, April 18, 1912), pp. 481-505.

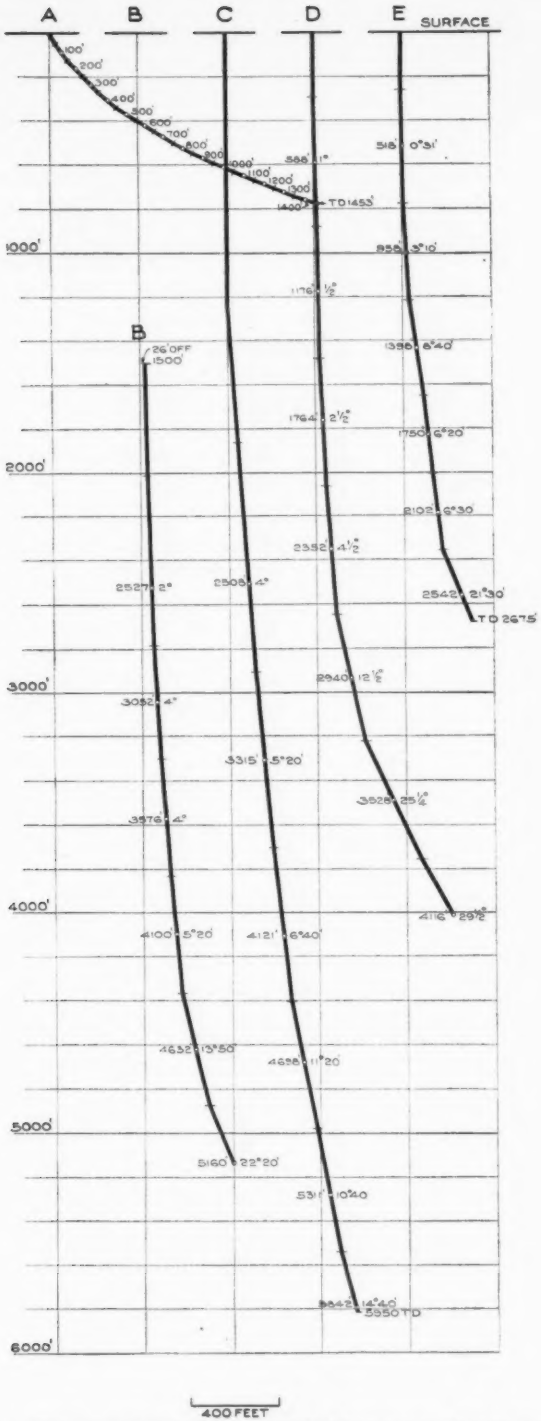


FIG. 2.—Examples of crooked holes, all plotted from same surface line and assumed to deviate in same vertical plane. *A*, diamond drill hole, started at angle to vertical. *B*, *C*, and *D*, three holes from the Texas Gulf Coast; *E*, a well from the interior East Texas region.

fontein No. 26, in the Heidelberg District of the Transvaal, and second, a hole(3) on the part of Witpoort No. 162 belonging to the South African Lands and Exploration Co., Ltd. The former was carried to a total depth of 6,656 feet, and the latter to 5,600 feet. We have reproduced Hoffman's illustration of the deeper hole (Fig. 3). This hole was surveyed by Oehman's apparatus (see p. 1147), which records both the angle of inclination and the direction of inclination of the boring. As may be seen by Figure 3, the direction of deviation was nearly constant, toward the northeast. The hole was straight to a depth of 1,000 or 1,200 feet. Then it rapidly turned through angles increasing up to 44° at 2,600 feet, after which it maintained a nearly regular slope between 42° and 58° to a depth of 6,600 feet. As a consequence of this deflection, this point, at 6,600 feet, was calculated to be 3,632 feet horizontally from the mouth of the hole and about 5,050 feet vertically below the mouth of the hole. Thus, assuming that the original desire was to bore vertically, an unnecessary excess of 1,550 feet was drilled.

Rotary holes.—In Oklahoma we have the following instances of rotary holes which were found to be crooked, or which were assumed to be crooked because of their abnormal behavior. These were drilled by the rotary method, using fishtail bits or cone bits for most of the digging. The first three examples are from the Seminole district. One well (4), which encountered the Viola lime at −3,297 feet, at an average depth of 200 feet lower than its three offsets, was an exceptionally good producer, both in its initial output and in its holdup.[1] Similarly, another well(5) produced 1,400 barrels, initial, although it was 350 feet lower on the pay sand than the dry holes surrounding the pool in which it was drilled.[2]

Figure 4 illustrates a hole (6) which was improved by plugging back and redrilling. This, like the foregoing examples, was in the Seminole field. The following is a quotation, in part, from a letter: "The first hole was drilled to a total depth of 4,519 feet. From 3,900 feet to that depth we had been looking for the Mayes limestone, which is one of the first definite markers we get in the Seminole area; but to the depth of 4,519 feet we had not yet reached this limestone, and became suspicious as to the condition of the hole. The pipe rotated very freely when drilling, and when breaking joints the table would spin, which is generally considered as an indication that a hole is in good condition. We ran" a

[1]J. L. Dwyer, "Crooked Holes Cost Industry Vast Sum," *Oil and Gas Jour.* (August 23, 1928), p. 29.

[2]Personal communication.

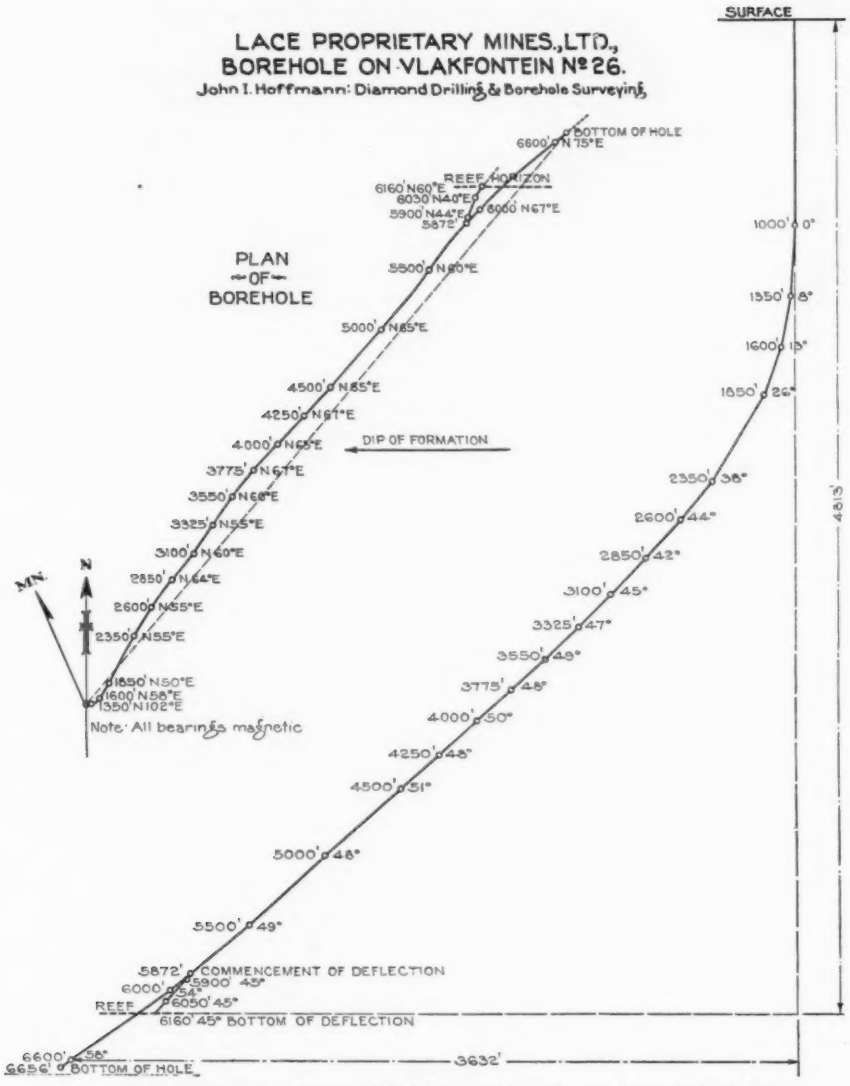


FIG. 3.—Course of a diamond drill hole in South Africa, seen in vertical and horizontal projections. After John I. Hoffman. Published by permission of the Institution of Mining and Metallurgy of London.

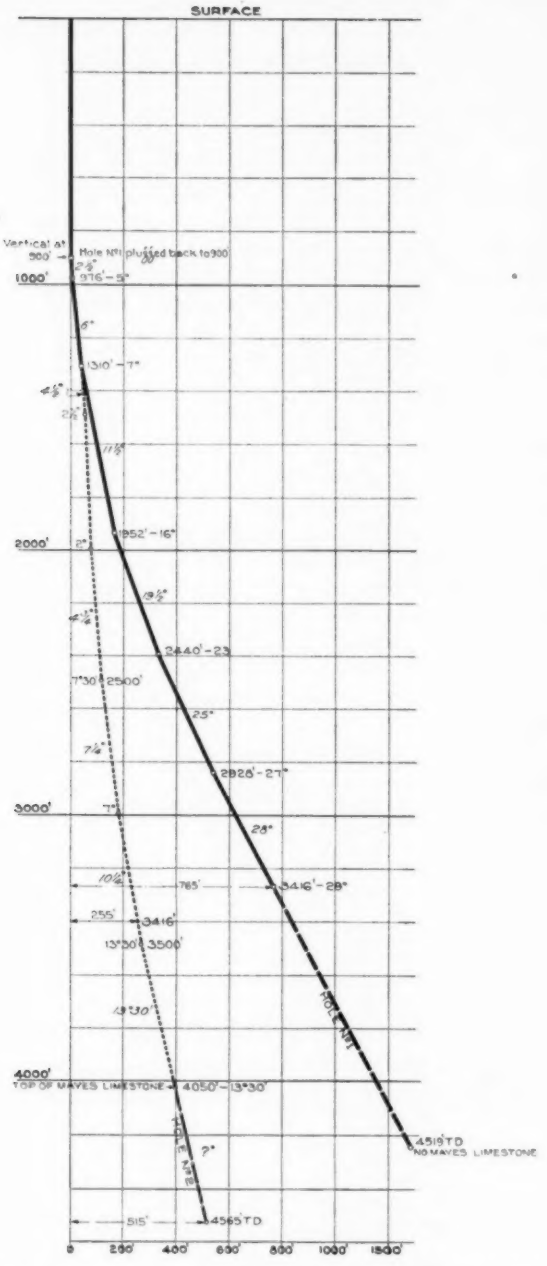


FIG. 4.—Course of a well in the Seminole field, Oklahoma. Plotted as if deviation were all in same vertical plane. The same method of plotting is used in Figures 5, 7, 11, 13, 14, and 15. All were surveyed by the acid-bottle method (see p. 1145).

series of acid bottle tests down to 3,904 feet. "This test was lost so that we do not know just how much the hole was out; but at 3,416 feet" the inclination from the vertical was 29°.

This first hole (6*a*) was cemented from 1,500 feet to 920 feet. After allowing time for setting, drilling was commenced again, using a fish-tail bit with a Reed reamer on top of the drill collar above the bit, and a second reamer, one joint above the first. At two or three points, the second reamer was removed where there was too much danger of caving, or where a rock bit was used. Acid bottles were run at intervals during the progress of the drilling. The angles recorded are given in Figure 4, hole 2. From 7° off plumb at 1,310 feet, the deviation decreased to 2° at 2,000 feet; but it gradually increased below 2,000 feet to 13½° at 4,050 feet, where the Mayes limestone was encountered. In the first hole(6*a*) this limestone was not reached at 4,519 feet. We can not say how much more drilling would have been required in hole 6*a* to reach the "pay," or, if this "pay" had been attained, whether water, rather than oil, would have been produced; but we do know that an unnecessary excess of nearly 500 feet was drilled in trying to find the Mayes limestone.

Two significant facts claim attention in this example. First, the behavior of the drilling tools gave no indication whatever of the pronounced crookedness of the first hole(6*a*). And second, by more care exercised in drilling, a much straighter hole was completed in the second attempt(6*b*).

From another personal communication, we received data which have been graphically recorded in Figure 5. This well(7) was in the Logan area. The angles were measured by the acid-bottle method (see p. 1145). The noteworthy feature in this case is the decrease in angular deviation after attaining a maximum of 29¾° at 1,250 feet. The person who gave us this information stated that frequently this tendency to return toward the vertical has been observed in crooked holes in the Logan district.

An extreme case reported from the Seminole district was that of a hole(7*a*) which, at a measured depth of 5,100 feet, had been drilled an unnecessary excess of about 800 feet and had migrated horizontally 2,470 feet, as estimated by the acid-bottle method.

D. R. Snow,[1] in a paper recently presented at a meeting of the Tulsa Geological Society, made the following significant summary of the data secured from acid-bottle tests of 90 wells in the Seminole area.

[1]D. R. Snow, "Cause and Effect of Crooked Holes," *Oil and Gas Jour.* (April 4, 1929), p. 109.

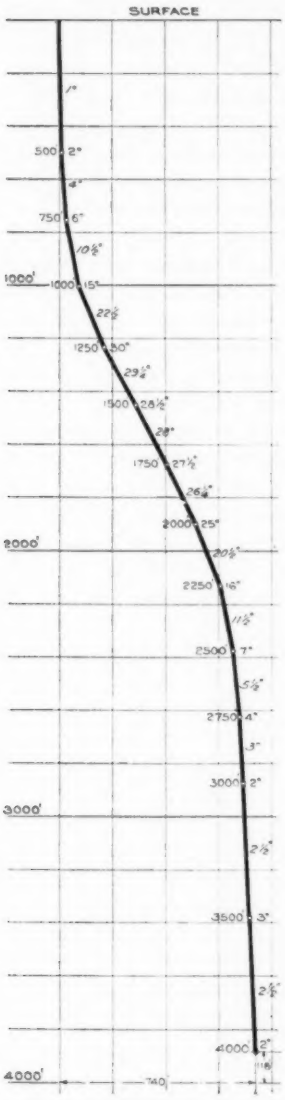


FIG. 5.—A crooked hole in the Logan district, Oklahoma (see title of Figure 4).

Vertical Deficiency in Feet	*Number of Wells*	*Number of Wells as Per Cent of Whole Number*
Under 25	20	22.25
25-50	9	10.00
50-100	28	31.10
100-200	24	26.60
200-300	4	4.44
More than 300	5	5.56

Out of the total footage drilled (377,719 feet) in these 90 wells, the total vertical correction was 9,290 feet, or an average of 103 feet per well.[1] At $10.00 per foot, this represents a loss of more than $90,000 in drilling operations alone.

Turning now to Texas, we show in Figures 2, *B*, *C*, and *D* the results of acid-bottle measurements of three wells (8, 9, and 10) in the Gulf Coast district.

Figure 6 illustrates a hole(11) drilled in East Texas. This hole had reached a depth of more than 4,000 feet before acid bottles were run. The drilling had been easy and with no suggestion that the string of tools, while in operation, was not essentially vertical. A preliminary survey, made by running a couple of bottles containing hydrofluoric acid in a string of three joints of 2-inch pipe, suspended on a sand line, convinced the operators that the hole was crooked. Elaborate preparations were then made for using an oriented drill stem in combination with the acid bottles. For a description of this method, see p. 1149. In Figure 6, the horizontal projection of the course of the hole is shown on the right. These bearings are correct only provided the drill stem, which was surveyed fourble by fourble at the mouth of the well, did not acquire any twist at its lower end when suspended in the well. The graph at the left (Fig. 6) represents the course of the hole, each measured angle being recorded in the same vertical plane. In other words, no correction has been made by rectangular projection of the angles, measured in the several azimuths, into a vertical plane fixed in its bearing. This explains the discrepancy in horizontal displacement indicated in the two diagrams—800 feet in one case and 835 feet in the other. The loss in vertical depth, due to the lean of the hole, is 135 feet at the measured depth of 3,806 feet.

Figure 2, *E*, is another example(12) from East Texas.

[1]It is interesting to note that the largest vertical deficiency so far recorded in the Seminole district was 798 feet.

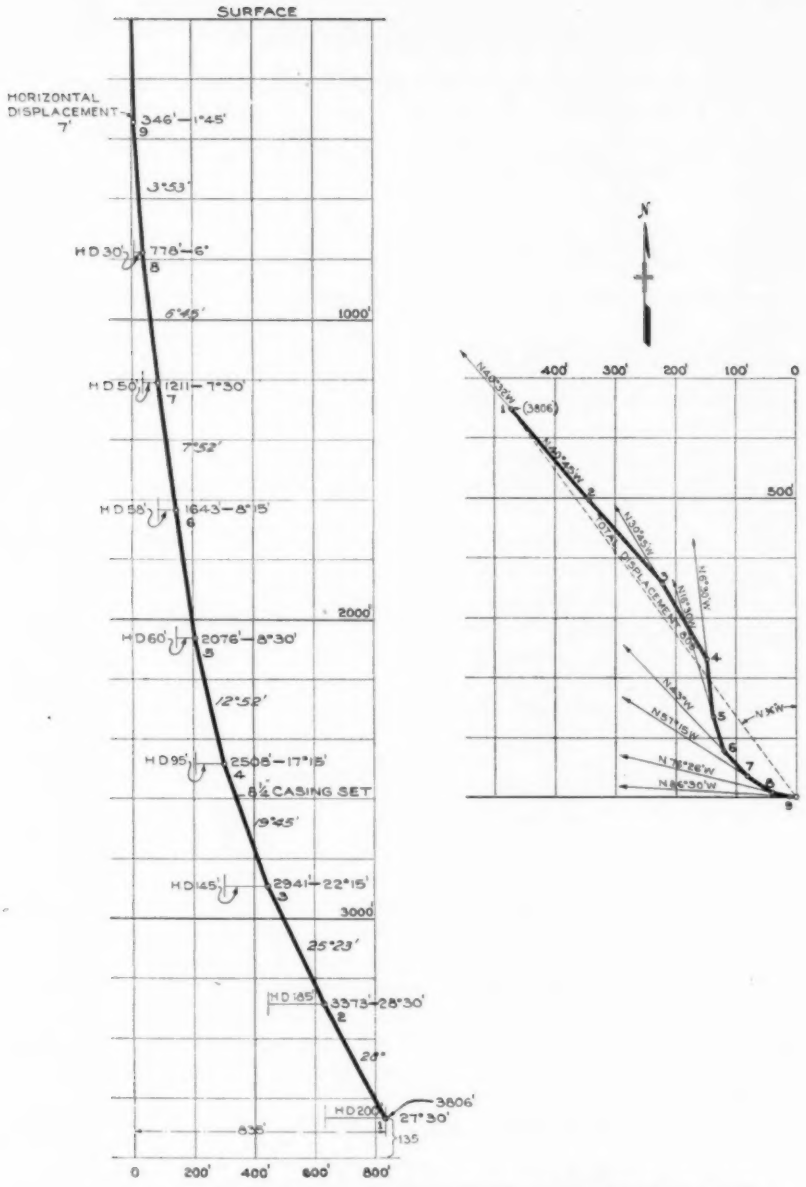


FIG. 6.—A crooked hole in East Texas. On the left is the vertical plot and on the right is the horizontal projection of this hole. The information was obtained by surveying with acid bottles in an oriented drill stem (see page 1148).

In Winkler County, in West Texas, several holes have been measured by the acid-bottle method. In one hole(13), after a depth of 2,950 feet had been reached, great difficulty was experienced, the hole seeming to be crooked. Two shots, one of 80 quarts and one of 30 quarts, were separately exploded between 2,865 feet and 2,915 feet in an attempt to help straighten the hole. The results were fairly successful, but at 3,100 feet, after drilling had been resumed, more trouble was encountered. At this point acid bottles were run, secured in the bottom of a bailer, to depths of 1,500 feet, 2,600 feet, and 3,050 feet. At the first depth the recorded angle was 2½°. At 2,600 feet, the hole was 15° off the vertical; and at 3,050 feet this angle had increased to 27½°.

In another well(14) in Winkler County (Fig. 7, *A*) acid-bottle readings were made at 400 feet, and every 100 feet down to 2,600 feet. At 2,683 feet a test showed 20° inclination from the vertical. At 2,715 feet this angle was reduced to 15°, possibly through corrective measures.

A third example(15) from Winkler County is represented in Figure 7, *B*. Here a maximum deviation of 41° was recorded at a depth of 2,200 feet. It is interesting to observe that the sharpest increase in deviation occurs near the passage from the Red-beds-anhydrite section into the underlying "Big salt," between 1,000 feet and 1,400 feet. Below 2,200 feet, the angular deviation becomes progressively less to 25° at 2,960 feet. If it is assumed that all the migration is in one vertical plane, the horizontal displacement of the bottom of the hole would be about 1,090 feet from the mouth of the hole, and the vertical deficiency, or loss in depth, would be 315 feet; but these figures are of course too great, since there is very little chance that all the wandering of the hole is in one vertical plane.

Early in November, 1928, 17 holes in the Hendricks pool, Winkler County, had been abandoned or plugged back and redrilled on account of their crookedness, at depths of less than 2,500 feet, that is, before reaching the pay zone.

Many interesting cases have been studied in California, where the measurement of crooked holes has been going on for several years. Figures 8 and 9 are from charts made by Alexander Anderson of a hole(16) which was drilled in Santa Barbara County. Numerous twist-offs induced the owners to have the hole surveyed. It was found to have migrated a horizontal distance of more than 200 feet at a depth of 2,300 feet.

At Hovey Hills a well(17) was discovered to be 425 feet off plumb at a depth of 2,550 feet. This hole, drilled where the formations had a steep dip, entirely missed the pay sand which it would have penetrated if it had been vertical.

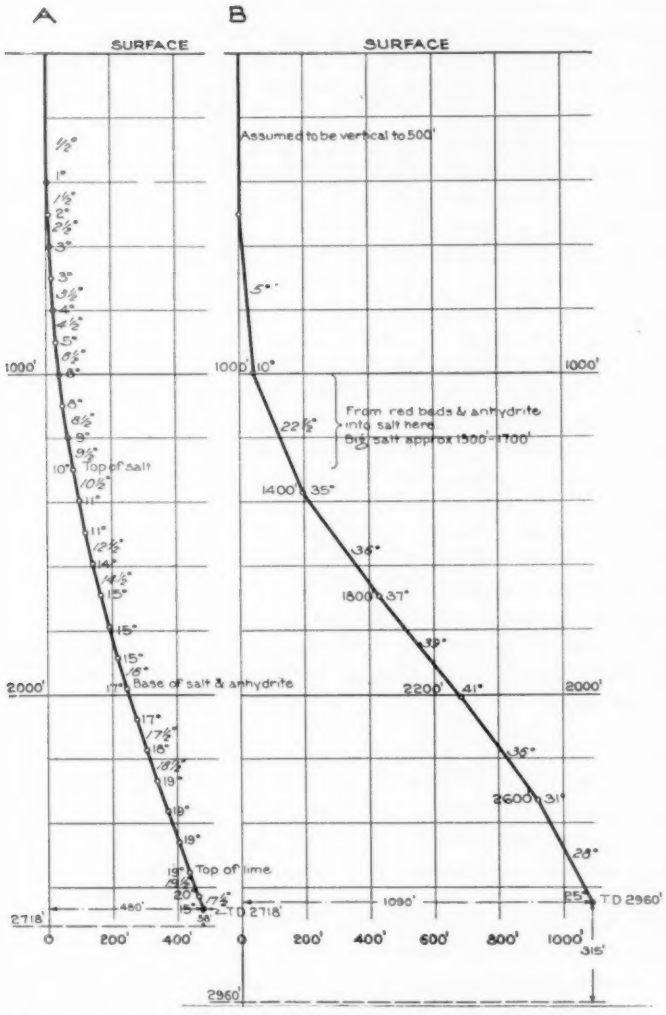


FIG. 7.—Two crooked holes in Winkler County, Texas (see title of Figure 4).

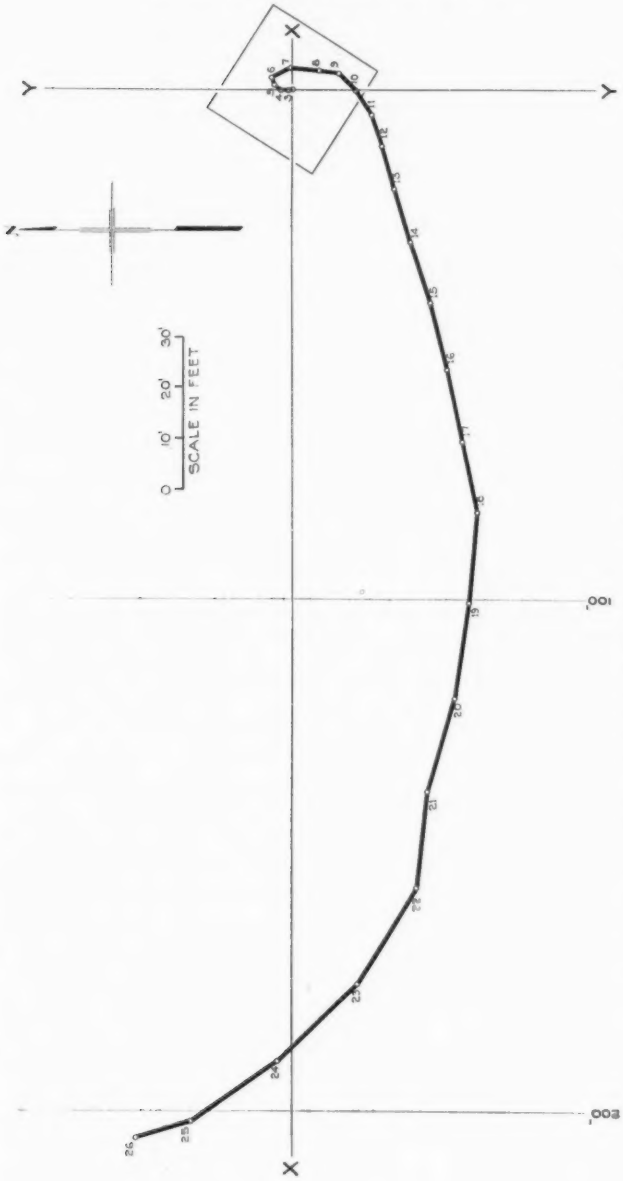


FIG. 8.—Horizontal plan of a hole in California surveyed by Alexander Anderson (see Figure 9).

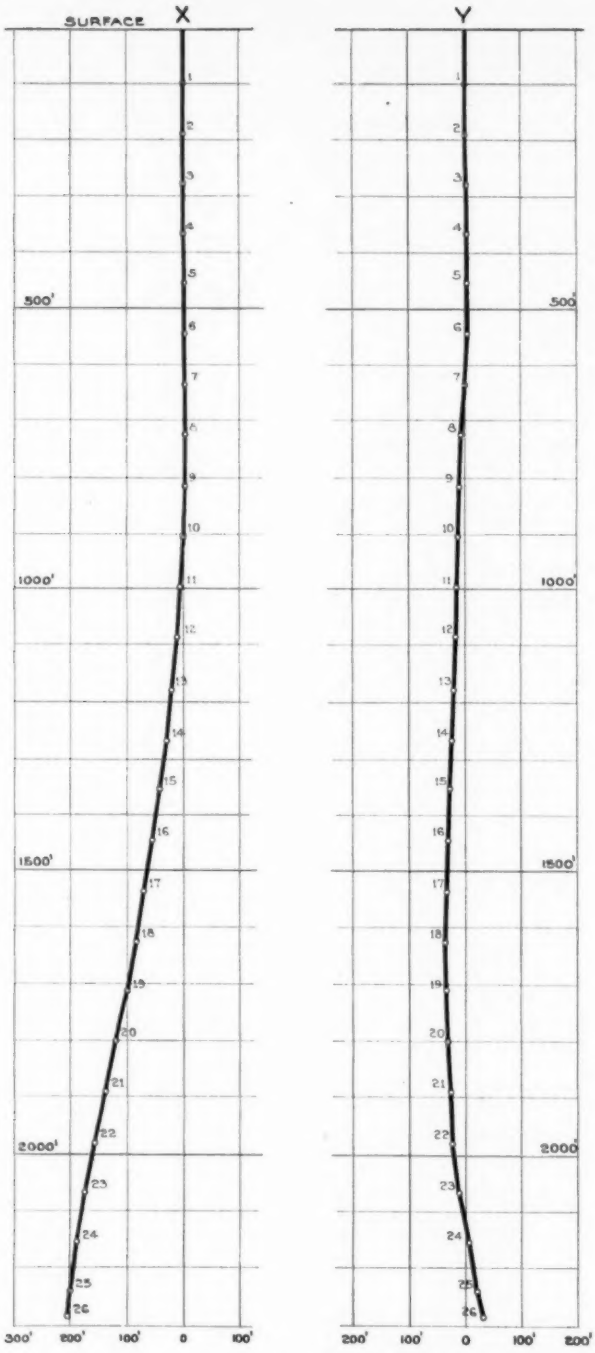


FIG. 9.—Same hole as in Figure 8, shown in two rectangular vertical projections along lines *X* and *Y* of Figure 8.

Considerable publicity has been given to Olinda 96[1] in Orange County, California, which in September, 1926, was the deepest well in the world. At 6,000 feet, this hole(18) was 571 feet off a vertical line through its mouth. Anderson points out that many of the marked changes in inclination and especially in direction of lean could be correlated with lithological variations in the formations.

In the Naples field, East Seal Beach, California, two wells were drilled on a small dome, one(19) being an edge well and the other(20) being located near the crest of the structure. The edge well produced 3,000 barrels initial, from 5,052 feet, whereas the well on top of the dome had an initial yield of only 1,000 barrels from the same sand, but at a depth of 5,503 feet. Apparently well 19 migrated up-dip, and well 20 migrated down-dip.

In a certain field in California two wells were located 100 feet apart on the surface. From one(21) of these holes (Fig. 10, *A*), cores showing lamination dips of 5° (85° to the axis of the core) were recovered from just below 6,000 feet. From the other hole(22), through the same depths, cores showing 60° dips were obtained (Fig. 10, *B*).

The following example of a crooked hole(23) in California is most striking. This hole was drilled to 6,410 feet. There were no twist-offs. The survey was made by Anderson, who could not use his instrument below 5,683 feet, so extremely crooked was the hole. At this point the inclination from the vertical was 56°; the vertical depth was 4,893 feet, or 790 feet less than the measured length; and the horizontal displacement was 2,252 feet.

Cable-tool holes.—Holes drilled by the percussion method are ordinarily more nearly vertical than are rotary holes; but, as we shall see, some of them may deviate at large angles.

E. L. Estabrook[2] cites a case in Wyoming. A hole(24) was drilled to 1,422 feet where a sand was encountered which would yield about 10 barrels per day. At 1,361 feet the casing stuck, indicating a crook at this point. After failure to straighten, the hole was plugged back to within 50 feet of the surface, and was redrilled. At 1,400 feet, where the same sand was encountered, the well began to flow.

In Pennsylvania, the Peoples Natural Gas Company drilled a cable-tool hole(25) known as their Ligonier No. 1842, on the Chestnut Ridge

[1]Alexander Anderson, "Underground Survey of World's Deepest Well," *Oil Age* (September, 1926). Also *Oil and Gas Jour.* (September 9, 1926), p. 29.

[2]"An Alibi for Geologists," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), p. 1295.

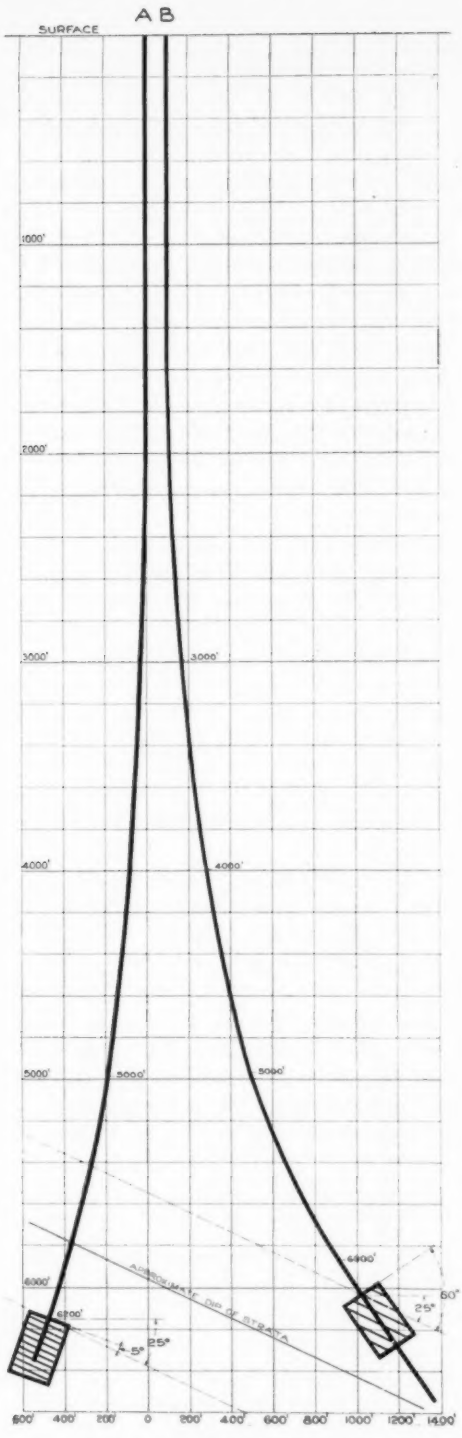


FIG. 10.—Ideal illustration of two holes in California which started 100 feet apart and eventually yielded cores showing dips of 5° and 60° from a depth of about 6,200 feet.

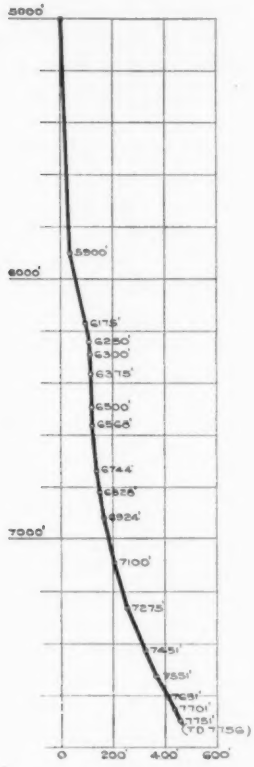


FIG. 11.—Lower part of a cable-tool hole in Pennsylvania (see title of Figure 4). The deviation is assumed to be in one vertical plane.

anticline.[1] The strata penetrated consist of alternating hard and soft rocks, and the dips are fairly steep. Acid bottles, run in the hole, indicated angles of deviation from the vertical shown in Figure 11. Down to a depth of 5,000 feet the hole was practically vertical, but with greater depth its inclination increased to a maximum of about 27° at 7,550 feet.

[1]L. E. Smith, "Crookedness of Deep Holes Determined by Acid-Bottle Method," *Natl. Petrol. News* (July 21, 1926), p. 50A.

J. French Robinson and J. G. Montgomery, "Deep Drilling in the Appalachian Field with Cable Tools," *Oil Field Engineering* (August 1, 1928), pp. 26-31.

J. L. Dwyer[1] mentions a hole (26) which was drilled by rotary tools to about 3,500 feet, where it was 20° off plumb. Cable tools were then substituted, and drilling continued to 5,100 feet. At this depth the deviation was 33° from the vertical. The cable tools had not helped to straighten the hole.

In California last year a hole(27) was drilled by cable tools to 1,457 feet (Fig. 12). Then rotary equipment was installed, and drilling continued to 3,073 feet, where cores with dips nearly parallel with the axis were secured. A survey, made by Anderson, revealed that at 1,457 feet the hole had drifted only 25 feet, whereas at 3,073 feet the bottom was 547 feet horizontally from the mouth of the well. Standard tools were again installed, and the hole was redrilled from 1,457 feet to 3,020 feet. The bottom of this new hole was only 113 feet out of plumb from the mouth. In this instance, then, cable tools distinctly bettered the condition of the hole.

In Kansas a wildcat well(28), located a little west of the axis of the structure, was drilled by rotary to 4,000 feet. At this depth it was found to deviate 14° from the vertical, although a maximum angle of 21° was recorded higher. Figure 13 diagrammatically represents this well. We do not have the acid-bottle readings above 4,000 feet. At this depth, cable tools were installed. At 4,855 feet, the top of the "Mississippi lime" was encountered and from March 3 until December, 1928, drilling continued in this same formation, down to a total depth of 5,358 feet. Acid-bottle tests showed a deviation increasing to a maximum of 34° at 5,358 feet. Two attempts were made to straighten by shooting, but without signal success. The reduction in deviation at 5,037 feet resulted from the shooting. Observe that the cable tools did not reduce the angle of deviation even in the formations above the lime.

Intersecting holes.—The most astonishing results of the deviation of holes from the vertical are witnessed where wells run into one another far below the surface.

A. Beeby Thompson describes the case of two wells in Burma.[2] One was quietly producing on the pump when the tubing suddenly began to dance up and down in a rhythmical manner which was observed to synchronize with the motion of the walking beam of a near-by drilling well(30). The new well had been drilled into the pumper.

[1]J. L. Dwyer, "Crooked Holes Cost Industry Vast Sum," *Oil and Gas Jour.* (August 23, 1928), p. 29.

[2]Personal communication.

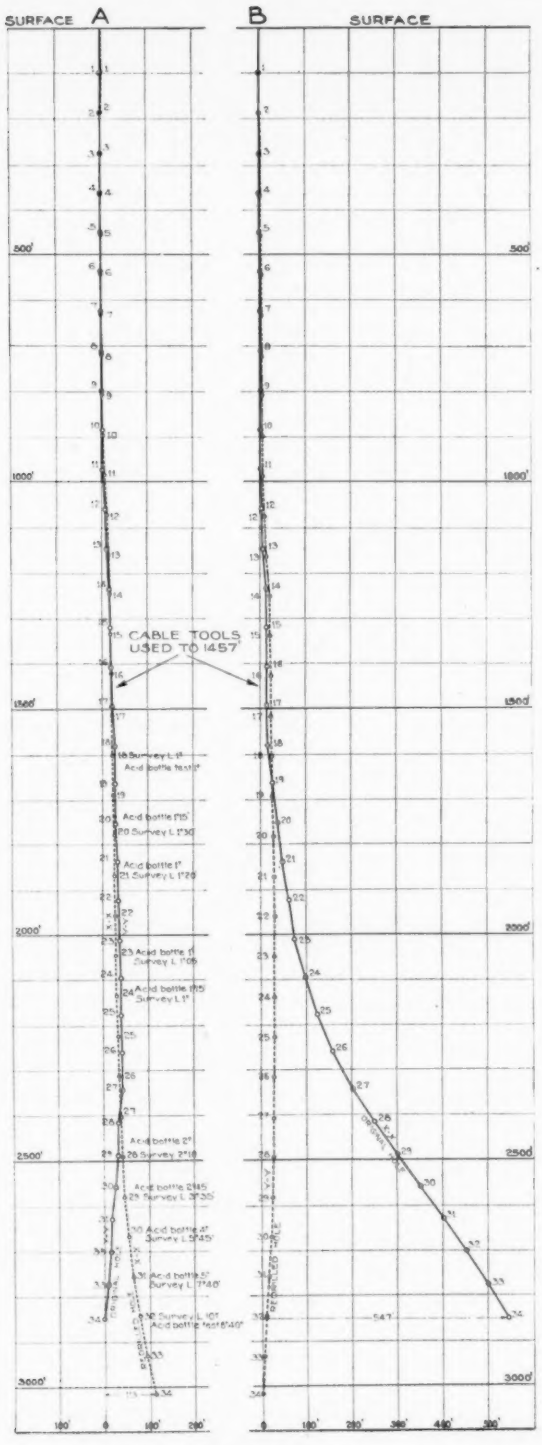


FIG. 12.—Rectangular vertical projections of the course of a hole in California. Surveyed by Anderson.

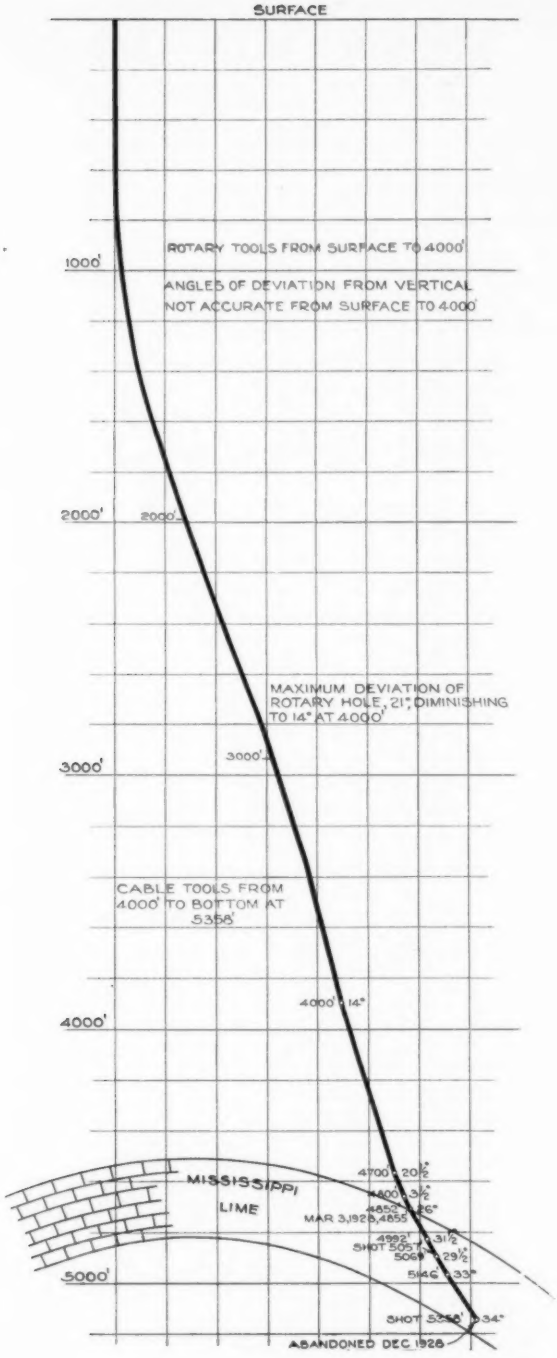


FIG. 13.—Plot of the course of a cable-tool hole drilled in Kansas (see title of Figure 4). The position of this hole on the east (right) side of the anticline is merely assumed.

On the Texas Gulf Coast, on one of the salt domes, a certain well(31) was drilling at about 3,600 feet when an offset well(32), 100 feet distant, ran into the former hole at about 2,200 feet. In both wells the drill stem began to jump and bounce as if the bit were on a boulder. Presently well 32 lost its returns.

The drill stem was then lifted in well 31 with the result that the drill stem in 32 rose a few feet. When the stem was pulled out of 31, it was discovered to be cut nearly in two. Next, the pipe was lowered in 32, and it went a full fourble below the depth at which 32 had been drilling. When the pipe was run back into 31, it wedged against the pipe in 32 in such a manner that the string of pipe in 32 was again raised when the pipe in 31 was lifted. After several unsuccessful attempts in 32 to plug back and sidetrack, this hole was eventually abandoned, and a new hole was started.

In Figure 14 we have drawn an ideal interpretation of a well-known example of two intersecting holes in Oklahoma. They were drilled 660 feet apart in one of the Seminole pools. Well 33 (Fig. 14, *A*) was drilling at 2,700 feet and well 34 (Fig. 14, *B*) was drilling at 1,900 feet when *A* began flowing mud and *B* lost returns. *A* was shut down while *B* was cemented back two or three hundred feet. While *B* was waiting for cement to set, *A* was drilled deeper, and without any difficulty, but after drilling began again in *B*, various troubles ensued. The drill stem in *A* was cut in two, and bit cones were lost in *B*. Finally, the lower part of the severed drill stem was fished out of hole *A*, and also, from this same hole, the cones lost in the other well, *B*. Both holes were abandoned.

In the Long Beach field, in California, two wells(35, 36) ran together at 2,100 feet,[1] but these were only 45 feet apart at the surface.

Two wells at Huntington Beach met under peculiar circumstances.[2] One(37) was producing on the pump, and the other(38) was drilling. Casing was landed in the new well(38), and cement was pumped in. The completed well ceased producing oil and when an attempt was made to pull the tubing, this was found to be cemented. The cement from well 38 had plugged the producer(37).

The really prime example, also from California, was that of two holes which started 2,000 feet apart on the surface (Fig. 15). Well 39 (Fig. 15, *A*) was drilling at 6,559 feet with 8⅝-inch casing set at 5,359 feet, and well 40 (Fig. 15, *B*) was drilling at 6,115 feet, it also having a string

[1] "Two California Companies Discover They Are Drilling in Same Hole," *Oil and Gas Jour.* (April 29, 1926), p. 181.

[2] "Migration of Rotary Drill Holes," *Standard Oil Bull.* (September, 1927), p. 12.

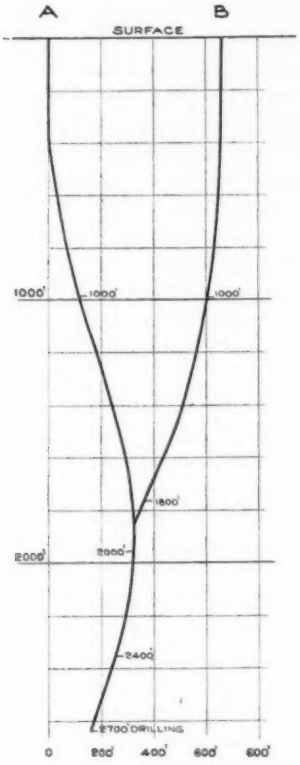


FIG. 14.—Two intersecting holes in Oklahoma (see title of Figure 4). The illustration is purely ideal.

of 9-inch casing set at 5,308 feet, when 39 lost its circulation and 40 began to gush a stream of mud. On the ground, well 39 is 86 feet higher than well 40. In the diagram both wells are shown to be equally culpable; actually, however, one may have deviated much more than the other.

In a paper read last February before the New York meeting of the American Institute of Mining and Metallurgical Engineers,[1] Anderson presented a summary of the results of his surveys of 255 rotary holes given in Table 1.

[1]Alexander Anderson, "Notes on Underground Surveys of Oil Wells."

TABLE I[1]

Drift and Inclination of Oil Wells

SOME DATA FROM UNDERGROUND SURVEYS OF 255 ROTARY DRILLED HOLES MAINLY IN CALIFORNIA. 1,158,542 FEET OF HOLE AND 13,150 INDIVIDUAL SURVEY READINGS (NOVEMBER, 1928)

Number of Holes	*A Depth in Feet (Measured Depth)*	*B Horizontal Distance from Mouth to Bottom of Hole in Feet*			*C Inclination of Hole from Vertical in Degrees and Feet per 100 Feet*			*D Amount of Drift from Vertical in Feet*			*E[2] B in Terms of Per Cent of D, Using Average*
		Maximum	*Minimum*	*Average*	*Maximum*	*Minimum*	*Average*	*Maximum*	*Minimum*	*Average*	
255	500	37	0	8.7	8°20′ 14.5	0°00′	2°09′ 3.8	114	0.0	10.6	82
255	1,000	131	2	30.2	15°30′ 26.7	0°00′	3°05′ 5.4	131	0.0	34.4	88
243	2,000	455	9	89.2	34°15′ 56.3	0°10′ 0.3	4°05′ 7.1	457	1.5	104.5	85
219	3,000	845	9	119.5	32°15′ 53.4	0°30′ 0.9	6°42′ 11.7	850	47.0	204.9	58
163	4,000	1,036	6	236.5	40°15′ 64.6	0°30′ °0.9	9°00′ 15.6	1,285	77.6	307.7	76
104	5,000	1,752	29	396.8	52°00′ 78.8	0°30′ °0.9	15°44′ 27.2	1,815	91.0	515.9	77
38	6,000	2,200	74	589.4	65°15′ 90.8	2°30′ 4.4	22°25′ 38.1	2,228	357.0	793.1	74

[1]This table, the surveys, the methods and apparatus employed are by Alexander Anderson, mining and petroleum engineer, Fullerton, California.

Explanation of terms:

B is the horizontal distance between a vertical line through the mouth of the hole and a vertical line to the hole at the listed depth.

C is the inclination from vertical at the listed depth.

D is the total drift from vertical down to the listed depth. It is the horizontal projection of the path of the hole, as seen from above. In the case of a well drifting in the same direction from mouth to bottom *B* and *D* would be equal.

[2]This column added by F. H. L.

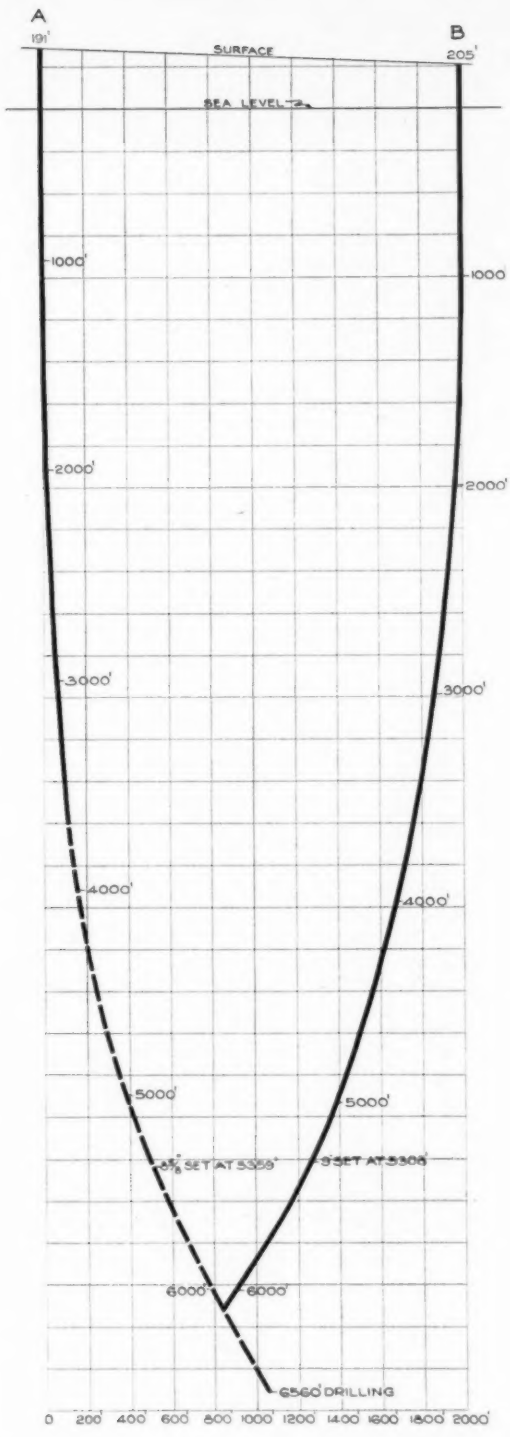


FIG. 15.—Two intersecting holes in California. The illustration is ideal.

Commenting on this summary, Anderson says:

> The inclinations and drifts shown as maximum in this table are limited by the fact that the survey apparatus was originally designed to record inclinations up to 54° from the vertical and was later modified to measure inclinations to 65° from the vertical. As a consequence, the largest inclination from the vertical is shown as 65° 15 minutes.
>
> In about a dozen of the rotary holes included in this table, the survey ceased after the holes had reached an inclination between 54° and 65° from the vertical, and the inclinations and directions of the lower portions of these particular wells are, therefore, not known.
>
> Some of these holes were uniformly increasing in inclination with depth, and it seems certain that several of them became horizontal or pointed upward at the bottom.
>
> Owing to the inclusion of an undue proportion of bad wells, the averages shown in "Table 3," both for drift and inclination, are probably about 25 per cent greater than the true averages that might be expected from a similar number of wells chosen at random in the same fields, and drilled at about the same date.

Particular attention is invited to the averages listed in column *B*. For these 255 holes, the average horizontal displacement of the bottom from the top was 120 feet at 3,000 feet, 237 feet at 4,000 feet, 397 feet at 5,000 feet, and 589 feet at 6,000 feet. Note also (Column *E*) that this straight horizontal displacement (column *B*) is generally between 75 per cent and 90 per cent of the total drift at the given depth.

COURSE AND SHAPE OF CROOKED HOLES

Much has been written concerning the course and the shape of crooked holes. As a matter of fact very little accurate information is available on this subject, especially in regard to holes drilled for oil, for the simple reason that very few wells have been surveyed by a precise method of measuring angles and directions of deviation.

The concensus of opinion seems to be that holes have a tendency to corkscrew in a clockwise manner, this being due to the clockwise rotation of the bit. Kitchin[1] states that this was the prevailing habit in 21 diamond drill holes which he described. Hudson and Taliaferro[2] state that sharp changes in lithology may cause sharp clockwise deflections in azimuth.

On the other hand, although some of Anderson's surveys in California exhibit clockwise spiraling of the hole (Fig. 8), many of them are

[1]Joseph Kitchin, *op. cit.*, p. 94.

[2]F. S. Hudson and N. L. Taliaferro, "An Interesting Example of a Survey of a Deep Bore Hole," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 775-85.

characterized more especially by irregular drifting. Several writers have declared that there is no tendency to corkscrew.[1]

The conclusion would seem to be that, while there is a mechanical tendency, due to the rotating bit, for the hole to corkscrew in a clockwise direction, actually this tendency may be weakened or entirely prevented from acting by local geological or mechanical conditions which are more effective than the mere turning of the bit. Whether the hole corkscrews, or wanders irregularly, the horizontal projection of the drift is commonly open, so that the greater proportion of the horizontal migration is in a fairly definite direction. In other words, when the drift is considerable, there is very small chance that the bottom of the hole will be near a vertical line through the mouth. This fact is brought out in column *E* of Table I.

Anderson[2] has pointed out that sharp changes in vertical angle are often accompanied by sharp changes in azimuth.

If the angle of deviation from the vertical is considered, as plotted in a vertical plane, a comparison of the figures shows that there is no pronounced habit. Thus, in Figures 2, *A*, *B*, *D*, and *E*, and 7, *A*, the hole turned at a constantly increasing angle from the vertical. In Figure 3, after a rather sharp bend, the course became fairly straight. And in Figures 5 and 7, *B*, the angle of deviation increased to a maximum and then decreased. It is probable that these variations were due to differences in the rocks encountered and differences in the mechanical condition of the drilling.

Another phase of this question of the course of the hole bears upon the relation between the direction of deviation and the dip of the bedding. This subject is both important and interesting.

One man experienced in diamond drilling, writes:

> If the bit strikes a very hard stratum at a very acute angle, it tends to follow along the plane of the stratum. If it strikes this hard layer at a fairly obtuse angle, the result is exactly the opposite.[3]

In Peele's *Handbook*[4] we read,

> When the angle between direction of hole and dip of strata is small, the hole tends to parallel the strata; when great, the tendency is to penetrate strata at right angles.

[1]See F. G. D. Muller, "Much Trouble Caused by Crooked Holes," *Oil Weekly* (April 19, 1924), p. 27.
Also R. Van A. Mills, "Crooked Holes Discussed by Engineers," *Oil and Gas Jour.* (August 23, 1928), p. 30.

[2]Alexander Anderson, *op. cit.*, *Oil Age* (September, 1926).

[3]Personal communication.

[4]Robert Peele, *Mining Engineers' Handbook* (1918), p. 369.

Kitchin[1] states that all the 21 diamond drill holes which he studied in detail were deflected in an up-dip direction with reference to the strata. W. F. A. Thomas, in the discussion following Kitchin's paper, emphasizes the same fact.[2] Even in cable-tool drilling, an up-dip migration has been observed.[3]

This is easy of explanation. If the rotating bit, which has been drilling in a soft formation, encounters a hard resistant layer, and if the beds have a moderate dip, the up-dip edge of the bit is checked, while the down-dip edge is still in soft material (Fig. 16, *A*). If there is any play between the drill stem and the hole, as there generally is, this resistance tends to cause the stem to bend under weight and to bow down-dip, so that the bit is cutting more nearly perpendicular to the bedding. The bigger the hole is in relation to the size of the drill stem, the more opportunity would there be for this effect. On the contrary, if the strata dip steeply, such a hard layer would function like a wedge, forcing the bit to slide down its face while continuing to cut in the soft rock (Fig. 16, *B*).

Whether the bit has the tendency to cut in an up-dip direction or in a down-dip direction depends upon the relations between several factors, such as size of hole, size of bit and drill stem, weight of bit, dip of bedding, difference between resistance of soft and hard layers, et cetera.[4] L. J. Black describes the influence of hydraulicking in causing down-dip migration.[5]

EFFECTS OF CROOKEDNESS OF HOLES

The effects of the crookedness of holes are of several kinds: some are mechanical; some concern production; some have to do with engineering practice; some are purely geological; and so on. A majority of these effects, however, can be classified as either mechanical or geological. Ultimately all of these are directly or indirectly financial.

Mechanical effects.—We are not going to enter into detail regarding the mechanical effects of crooked holes, since this is more properly a subject for consideration by others than geologists. Nevertheless, we should be neglecting a very important phase of our discussion if we should omit this topic.

[1]*Op. cit.*, p. 91.

[2]Joseph Kitchin, *op. cit.*, p. 132.

[3]Communication from Roy O. Armstrong.

[4]H. B. Goodrich, "A Compilation of All Published Matter Regarding Surveying of Deep Borings"....under title "Crooked Hole Problem Being Studied," *Oil and Gas Jour.* (November 15, 1928), p. 114.

[5]*Oil and Gas Jour.* (November 29, 1928.)

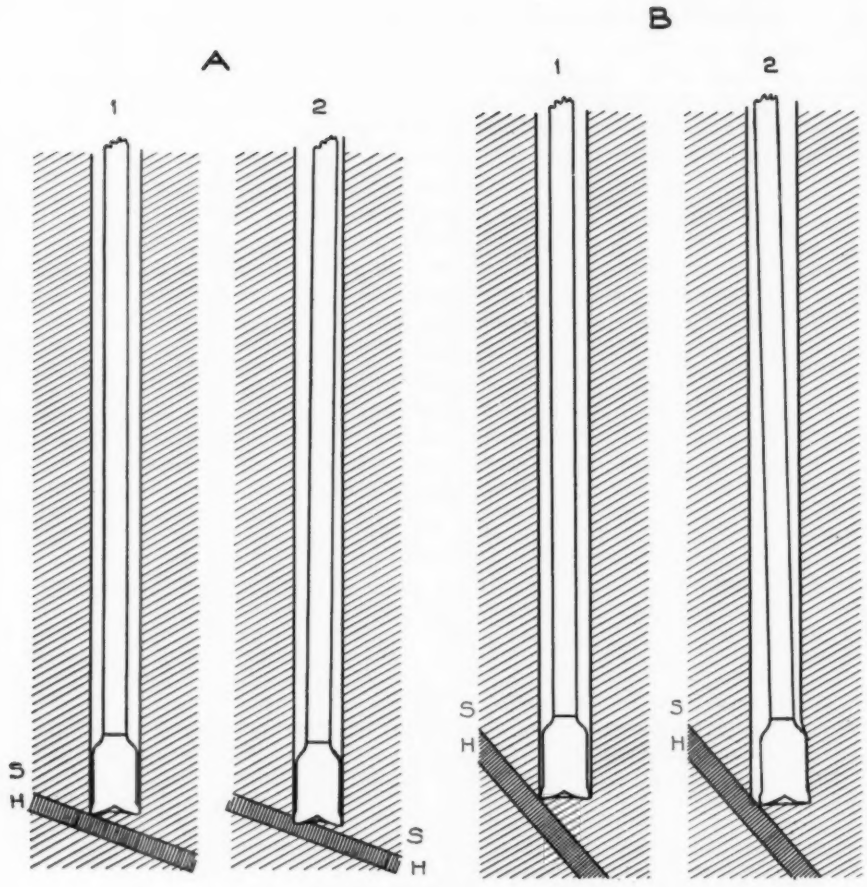


FIG. 16.—Figure to illustrate the effects of a gently dipping (*A*) and a steeply dipping (*B*) hard layer (*h*) in deflecting a rotary bit, thereby causing the hole to deviate from the vertical.

Mechanical troubles are exaggerated by rather abrupt changes in the course of the hole. Where the deviation takes place in a broad curve, difficulties may not be experienced, or they may be so slight that they escape notice; but whether observed or not, in every hole which is off the vertical there must be more or less irregular wear.

As a result of bends in the hole, the drill stem may twist off. Difficulties may be experienced in running the drill stem, in pulling out the drill stem, in running casing in open hole, or in running one string of casing in another. The pipe may collapse or part. The sides of the hole may cave, due to rubbing. Where a steel cable is used, as in cable-tool drilling or in swabbing operations, the cable may wear through casing which has been set. After a well has been put on the pump, there may be trouble with broken rods and rod-cut tubing.

Other mechanical difficulties might be mentioned. Throughout the entire process, almost from the time the hole is spudded in until it is completed as a well, and from the time it begins to yield until it ceases to be a commercial producer, these mechanical difficulties in connection with crooked holes are numerous and sundry. Obviously their cost must involve large sums of money.[1]

Geological effects.—Under the term "geological" we are including all those effects of the crookedness of holes which may be related to geological deductions and recommendations concerning possibilities of production, or to interpretation of geological structure, or to other similar subsurface conditions.

In the light of what we now know about the deviation of bore-holes the care with which well locations are measured off and surveyed on the ground becomes almost a joke. Arguments are not uncommon as to a choice between two points as little as 50 feet apart, for the location of a hole to be drilled to a depth of 3,000 feet or 4,000 feet. Indeed, how often is it not true that a location is surveyed just one foot more than the required distance in order to insure the correct offset spacing!

Figure 17 is a diagram to illustrate a possible spacing of the bottoms of six holes which on the surface are assumed to be 660 feet apart. The

[1]For further information on this subject see:
F. G. D. Muller, "Much Trouble Caused by Crooked Holes," *Oil Weekly* (April 19, 1924), p. 27.
H. B. Goodrich, "A Compilation of All Published Matter,"....(1926), *Oil and Gas Jour.* (November 15, 1928), p. 38.
R. Van A. Mills, "Crooked Holes," *Oil and Gas Jour.* (August 23, 1928), p. 30.
J. L. Dwyer, "Crooked Holes Cost Industry Vast Sum," *Oil and Gas Jour.* (August, 23, 1928), p. 29.
E. J. McKee, "Some Causes and Effects of Crooked Holes," *Oil Weekly* (November 23, 1928), p. 60.

arrows show the supposed direction of the horizontal migration of these holes, and the amounts are indicated beside the arrows. None of these quantities is extreme. Now imagine that the petroleum engineer is going to use the production figures from these wells to study the decline of production, or to estimate the per-acre yield of a particular property, or to investigate problems of porosity and the rate of flow through the sand, or to plan a logical system of repressuring, or to undertake a dozen

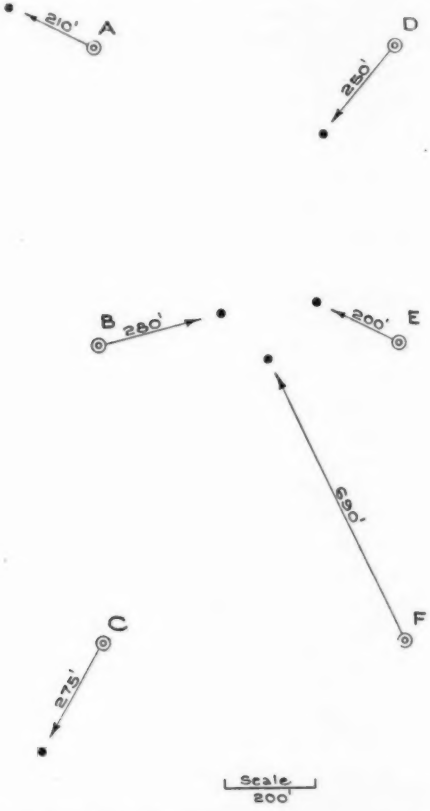


FIG. 17.—Example of six holes, started on the surface (double circles) with an offset distance of 660 feet. It is assumed that the holes deviate in the direction of the arrows so that the pay sand is encountered at the black spot at the horizontal distance indicated from the mouth of the well.

other similar problems, all of which are fundamentally premised on the measured spacing of the wells at the surface of the ground—truly, for the satisfactory solution of these engineering problems we must either drill our holes vertical or we must know their real location underground.

There is little question that many of the reported cases where offset wells exhibit remarkable effects of production rise or fall, as if the sand were very porous between the two, or as if they were connected by open channels—that many of these cases are due to the close proximity of the wells at the pay sand depth.

One of the lines of scientific research now under serious investigation, which promises to be of practical value as an index to subsurface uplifts, concerns temperature measurements in wells. Those who are engaged in this research are naturally anxious to secure records in deep wells. Unless they know the vertical depths of their points of measurement and the actual positions of these points on the structure, many of their readings, and particularly their deep readings, will be much in error.

Figures 18 to 22 illustrate several anomalies and misinterpretations which may easily result from the deviation of holes from the vertical.

In Figure 18, holes *A*, *B*, and *C* were drilled 300 feet apart in a region underlain by strata with a monoclinal dip. Oil sands, where present, are lenticular, containing oil toward the up-dip edge and water toward the down-dip edge. *A* should have been a good well, *B*, a good oil well with gas, and *C* a dry hole, in which the pay sand was absent. As drilled, *A* is a good well; *B* entirely missed the upper water sand and the oil sand, encountering a lower water sand; and *C* was a well producing oil and gas in the pay sand.

In Figure 19, *C*, between two wells, *B* and *D*, should have produced oil; and *G* should have been dry. As shown, however, *C* would have been a puzzle since it was dry and apparently missed the "pay" altogether. *G* was a surprise in that it was a much better well than *F*. An actual example of this kind was described on p. 1113 (wells 19 and 20).

Figure 20 illustrates one side of a salt dome in cross section. If the four wells had been vertical, *A* would have been a deep edge well; *B* and *C* would have been good producers; and *D* would have gone into salt several hundred feet above the "pay." Due to the deviation of these holes, *C* was an edge well, *A* and *D* were big producers, and *B*, between two oil wells, went into salt.

It is plain, in the light of these illustrations, that a wildcat well, located on structure, might easily drift off and miss an oil-bearing sand, especially where drilling is deep.

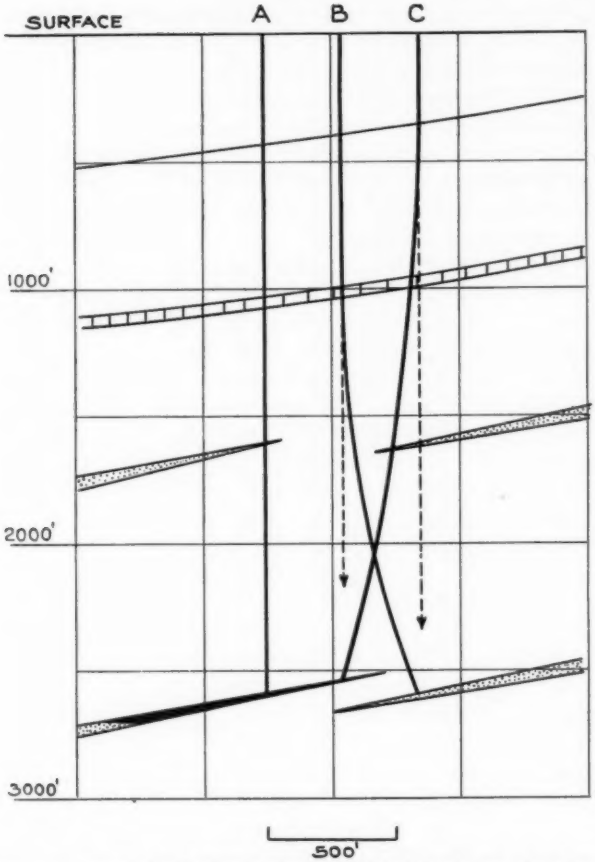


FIG. 18.—Suggested misinterpretation of geological data where the oil occurs in lensing sands with monoclinal dip. The wells are not supposed to intersect, but are projected onto the plane of the diagram. The same is true of Figures 19, 20, and 22.

In a hole which has acquired even a moderate angle of inclination from the vertical, erroneous estimates of the thickness of the formations penetrated are possible, and, consequently, incorrect figures may be given for casing seats in subsequent wells; the oil sand may be partly or wholly cased off; or, on the other hand, a water sand may not be completely shut off.

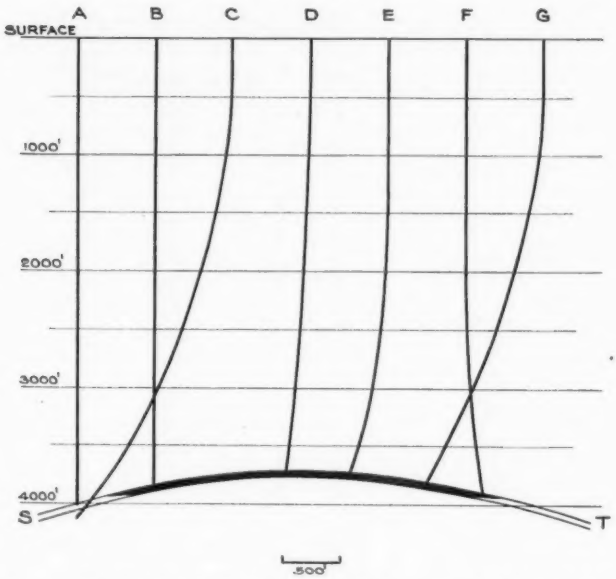


FIG. 19.—Possible effects of crookedness of holes on productivity of wells (see title of Figure 18).

Subsurface contour maps are based on the assumption that the key horizon was penetrated vertically below the mouth of the well. The elevation of the key horizon in each well, either above or below sea-level, is obtained by referring this assumed vertical depth to the sea-level elevation of the mouth of the well. If the hole is crooked an error is introduced into the calculated elevation of the key horizon, and this error may be large. In the Seminole field, the greatest recorded vertical discrepancy at a depth of 4,000 or 4,100 feet was 798 feet. The average for 90 wells is recorded in Snow's table, p. 1107.

No doubt in a majority of wells, taking into consideration all producing regions, this vertical error is relatively small; but it may be large without any suggestion of crookedness of the hole in drilling. Consequently holes should be surveyed for satisfactory contouring. The vertical error should not be greater than the contour interval. In maps covering small areas, or single pools, drawn on a large scale, considerable errors may creep in, unless, as is commonly the practice, the data from "freak" wells are omitted, but regional maps, constructed on data from

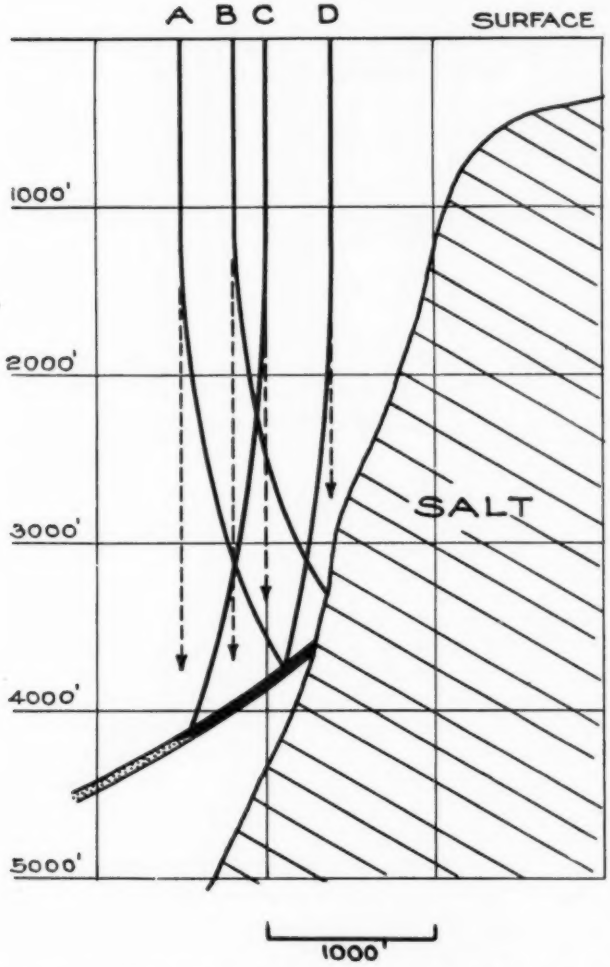


FIG. 20.—Suggested effects of crookedness of holes drilled on the flanks of a salt dome (see title of Figure 18).

wells which are many miles apart, suffer very little from the incorrect values obtained in crooked holes. The holes must be deep and far off the vertical to cause any serious misconstruction. And in any event, such maps should always be properly used and read with an open mind.

In Figure 21, five holes are shown in vertical section. From measurements in these holes, from the surface down to the key horizon, *RST*, the structure represented by line *VW* was inferred. Actually, however, the structure was that indicated by the full line, *RST*. The misinterpretation was due principally to the abnormal depth at which holes *B* and *C* reached the key horizon. It is easy to appreciate how an oil pool 1,500 to 2,000 feet wide might have been missed between *B* and *C*.

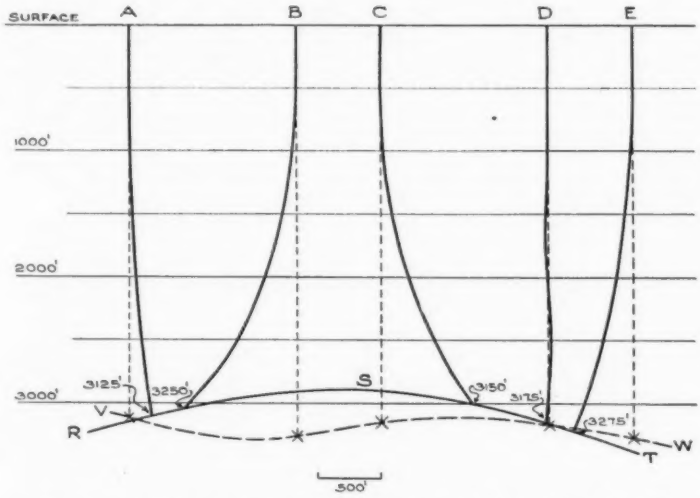


FIG. 21.—Possible misinterpretation of structure, due to deviation of holes from the vertical.

Figure 22 is another example of false interpretation. Here the excessive depth of hole *B*, at the key horizon, *RMW*, led to the conclusion that a fault of approximately 400 feet displacement lay between *B* and *C*, the strata on both sides of the fault having a dip toward *W*. Yet actually *RMW* is an unbroken anticline.

A phase of this problem in which the geologist is vitally interested, not for the mere scientific information which it may give, but for the very practical value which attaches to it, is the correct orientation of

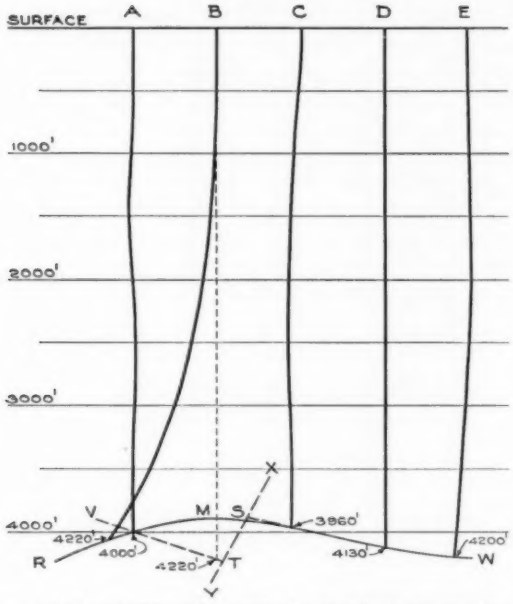


FIG. 22.—Another possible misinterpretation of geologic structure due to deviation of holes from the vertical (see title of Figure 18).

cores. In diamond drilling for hidden structure, cores are obtained for study. In our modern rotary drilling, most companies require cores at frequent intervals. Even in cable-tool drilling, devices are being perfected for securing cores. Generally, it is true, these cores are used for simple correlation from well to well; but where they exhibit stratification or cleavage or faulting or other similar rock features, we should be able to orient the cores. If the hole was vertical, we ought to know which part of the core faced north. If the hole was inclined, we ought likewise to know its azimuth and which part faced upward, toward the "hanging" side of the hole, to use a mining term. Very valuable information could often be secured if we could determine the orientation of such cores.

As a suggestion of problems of this type, we have drawn Figures 23 and 24. In Figure 23, the hole was drilled in inclined strata. Cores taken at four points all revealed dips of about 30°. Without being able to determine the orientation of these cores, *A* would probably have been the interpretation; but the true relations, brought out by knowing the real position of the cores in the hole, are shown in *B*.

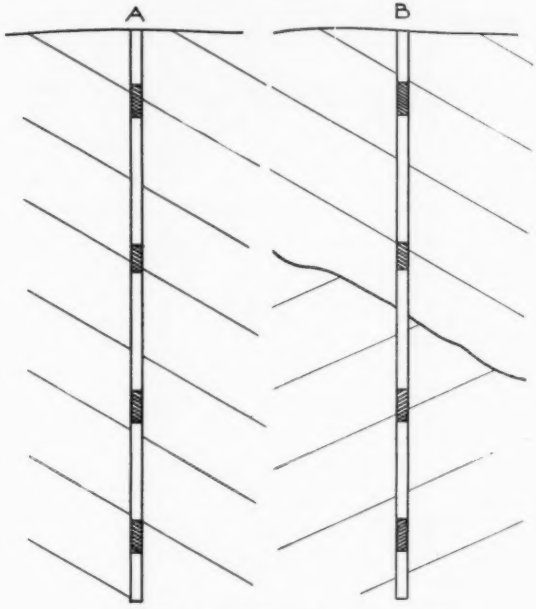


FIG. 23—Possible relations of cores to bedding.

Figure 24 illustrates a problem which actually occurred. A well was drilled on a flat dome. At a depth of about 3,500 feet, it abruptly passed into a series of beds with relatively steep dips which remained nearly constant to the bottom of the hole at about 4,000 feet. Assuming that the hole is vertical, did this lower series of beds dip west (*A*) or east (*B*) or in some other direction? If an oriented core had been obtained the operator would have known which way to go to drill into a higher part of the structure in this deeply buried formation.

The study of cores for their orientation and the determination of the direction of true dip is not easy. For instance, (1) in a vertical hole penetrating horizontal strata, the lamination is at right angles to the axis of the core. If (2) the beds are horizontal and the hole is inclined, the angle between the axis of the core and the lamination is equal to the inclination of the hole (Fig. 25). If (3) the beds dip, let us say, 30° due south, and the hole is vertical, the lamination in the core makes an angle of 30° with the axis of the core. But, unless the angle of deviation of

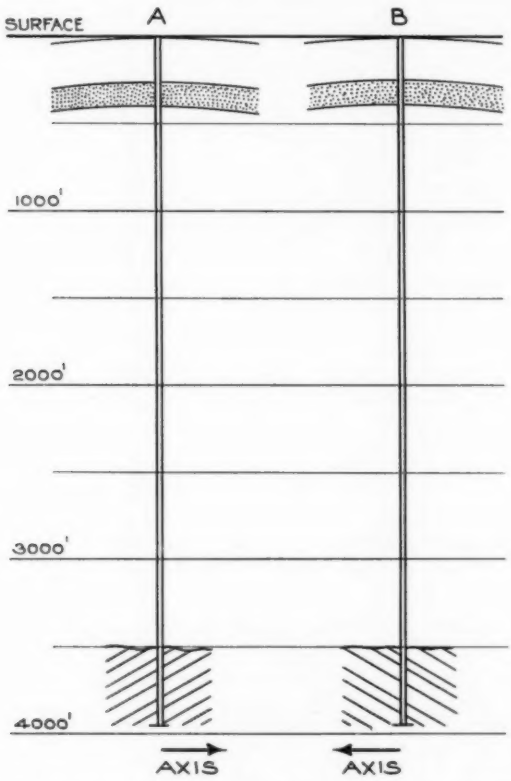


FIG. 24.—Two extreme interpretations of steep dips seen in cores from near the bottom of a well located on a surface anticline.

the hole is known in case (2) and unless the orientation of the core is known in case (3), we can not interpret the dip in the core.

Now if we suppose that (4) the beds dip 30° due south, as in case (3), and the hole is inclined 30° off the vertical in a due north direction, the core will show lamination perpendicular to its axis, as in case (1). Or, (5) the hole may be inclined more than 30° from the vertical in a due north direction, or (6) less than 30° due north, or (7) at an angle of less than 30° from the vertical due south.

These are all comparatively simple cases, for the hole is inclined in the plane of the dip of the strata. They are illustrated in Figures 25-27.

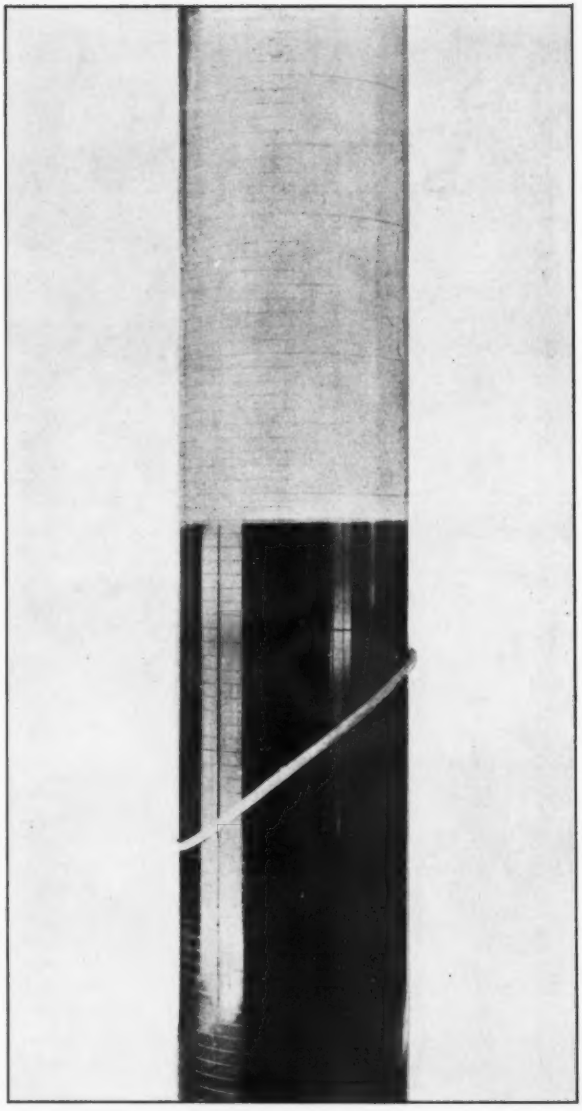


FIG. 25.—Illustration of dip in a core supposed to have been taken from a vertical hole. The glass tube represents the hole, the surface of the dark liquid marks the horizontal plane, and the strip of tape represents the bedding in the core.

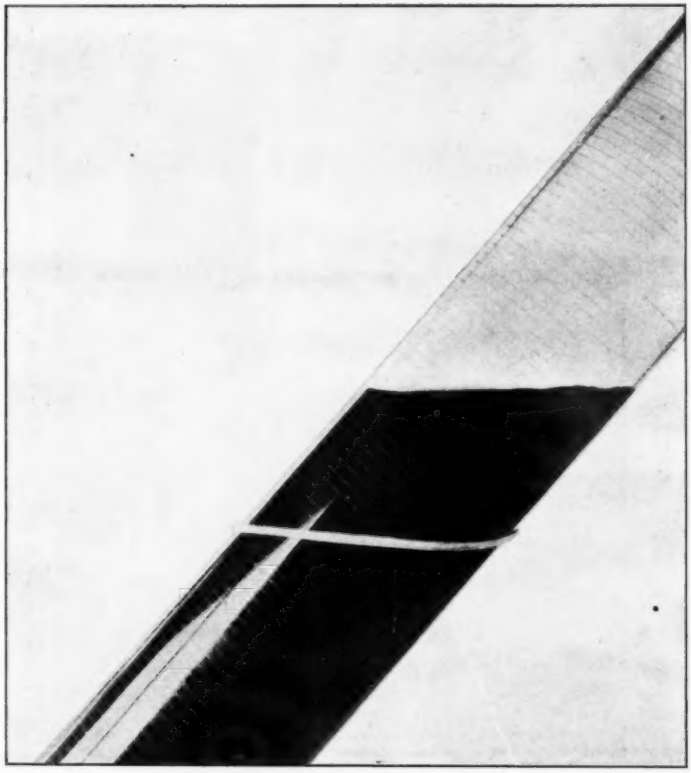


FIG. 26.—Similar to Figure 25, but here the hole (and core) is inclined in such a way that the bedding, actually about horizontal, would be said to dip the amount of inclination of the hole, if this latter figure were not known.

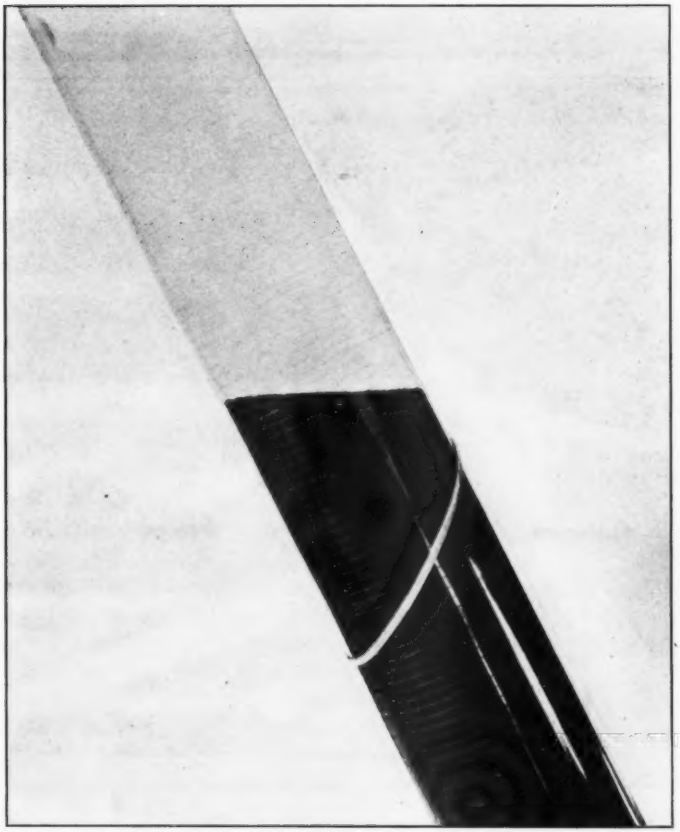


FIG. 27.—Similar to Figure 25, but dip is about 65° to left and hole is inclined about 30° off vertical toward right, giving impression of bedding dip of about 35°.

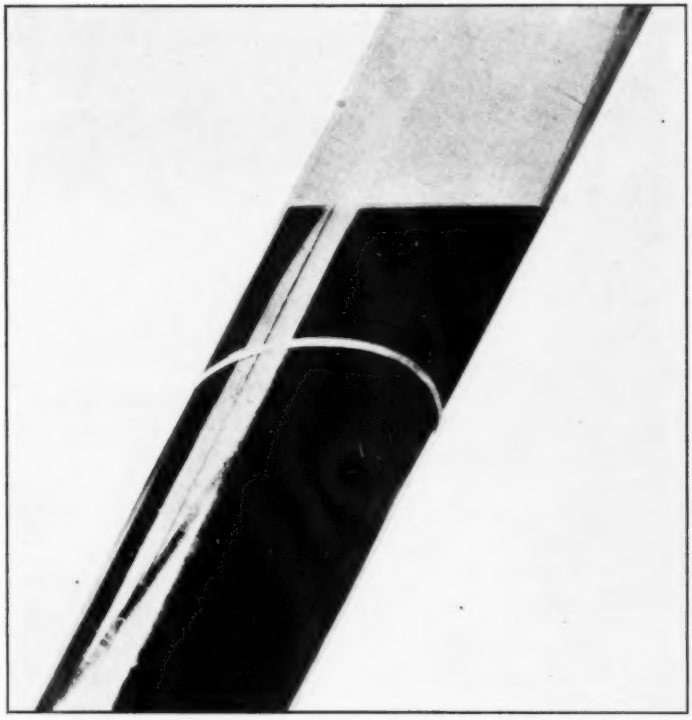


FIG. 28.—Similar to Figure 25, but here hole is inclined to left and bedding is inclined from front to back, in figure (see text).

The real difficulty lies in the fact that extremely few crooked holes are inclined in the plane of the dip of the bedding, even in the short length of hole from which the core came. Thus, in Figure 28, the core, represented by the graduated glass tube, slopes toward the left in the plane of the picture. The surface of the black liquid marks the horizontal line. The bedding (white line) dips toward the background, almost at right angles to the plane of the picture. It is evident from this picture that if the relations of the bedding (white line) to the horizontal plane and to compass directions were not known, nothing could be determined from the relations of the bedding to the core alone, and this is true even if the correct attitude of the hole were known.

This topic is stressed to make it thoroughly evident that oriented cores ought to be secured from drilling wells, but in order to secure them the hole must be surveyed as to both its angle and its direction of deviation from the vertical.

Figures 29-32 are photographs of cores. They are interesting, but their significance could not be fully determined because they were not oriented.

SURVEYING CROOKED HOLES

QUANTITIES TO BE MEASURED, AND DEVICES FOR MEASURING

In the present paper there is not space to enter into detail regarding the mechanism of the many kinds of instruments devised for surveying crooked holes, nor for describing the methods of calculating results. We intend only to outline the principles involved.

The quantities to be measured or surveyed are:

1. The angle of deviation of the hole from the vertical, determined at any given point or points along the course of the hole.

2. The direction, or azimuth, of this vertical angle of deviation, measured at any given point or points along the course of the hole.

3. The position of any such point or points in the hole, relative to fixed points on the ground.

4. The true attitude of bedding or similar geological features, from correct orientation of cores.

For determining merely the angle of deviation of a hole, the following devices have been used or suggested:

1. "Acid bottle," that is, a bottle partly filled with hydrofluoric acid and water, commonly in the proportion of 1 of acid to 3 of water.

2. Two pendulums pivoted to swing in vertical planes at right angles to each other; or one pendulum swung on a universal bearing.

3. A level bubble.

FIG. 29.—Core showing bedding perpendicular to axis of hole, therefore horizontal, if hole was vertical.

FIG. 30.—Core with moderate dip.

FIG. 31.—Core with steep dip. This was taken in a fault zone. The dip is drag. The isolated crystals are of pyrite.

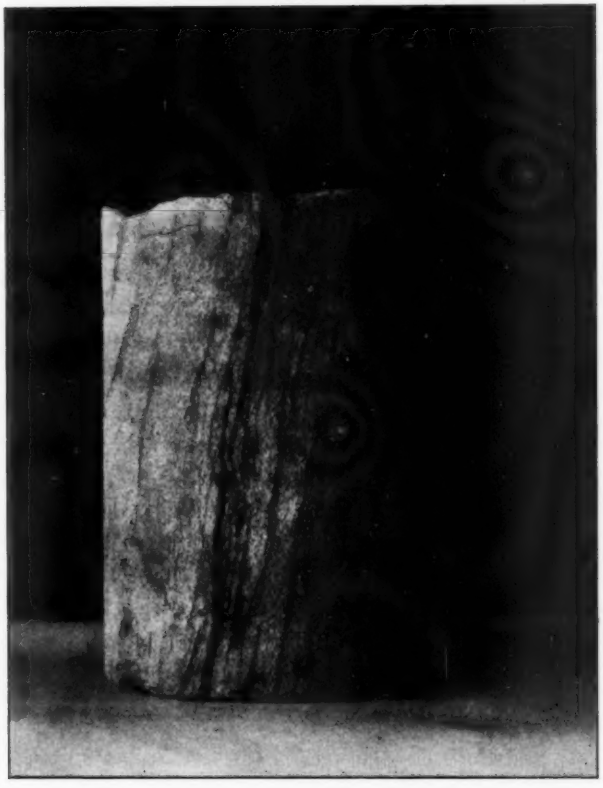


FIG. 32.—Core with nearly vertical dip (provided hole was vertical).

4. Mercury, making electrical contacts.

5. Principle of the Wheatstone bridge.

For measuring the direction of deviation of a hole, the following instruments have been used, generally in combination with one or another of the devices already mentioned:

1. Electric lights lowered into an open hole.

2. A drill stem carefully surveyed as to its azimuth at the mouth of the well.

3. A magnetic compass.

4. A gyroscopic compass.

5. Inertia of a heavy rotating body.

For recording one or more of the quantities measured by the instruments just cited, the following means have been utilized:

1. Photographic apparatus.

2. Bristles or clamps which are set at the proper time.

3. Pin pricks on a continuous tape, or on other record forms.

4. Gelatin or other similar substance which congeals about, and thereby sets in position, such a device as a compass needle.

5. Accurate surveying at the mouth of the well.

To operate some of these mechanisms, the following have been used:

1. Electric current, generated by a battery which is lowered into the hole.

2. Electric current carried from the ground surface by wires suspended in the hole.

3. Clockwork, timed to register automatically at the required depth, or depths.

4. Rotation of the drill stem.

For ascertaining the position of any point in a hole, some suggestions have been made or experiments have been conducted along the following lines of seismographic observation:

1. Setting off charges on surface, with seismograph in hole at required depth.

2. Setting off charge in hole, with several seismographs properly stationed around hole on surface.

3. Seismographic or geophonic registering of vibrations caused by drilling, especially cable-tool drilling, the instruments being placed at suitable distances from the mouth of the hole.

DESCRIPTION OF INSTRUMENTS AND METHODS

1. *The acid-bottle method.*—The simplest apparatus in use for determining the angle of deviation of a hole is the "acid bottle." A small

quantity of dilute hydrofluoric acid is poured into a glass bottle which is then tightly corked with a rubber stopper. The bottle is lowered into the well in a suitable container, commonly a length of steel pipe, which can easily be made small enough to run in a 6-inch drill stem. This container is securely capped and sealed against leakage from without. It is lowered in a few minutes at the end of a steel line, and is allowed to rest at the selected depth for 15 or 20 minutes, during which time the acid dissolves away a thin layer of glass, leaving a sharp line at the edge of the liquid. If the hole is inclined, this line is inclined, and its angle can be measured in the bottle after this has been withdrawn from the well and the acid poured out. The method is simple, but it is rather messy because rubber gloves are necessary and great care must be used lest the acid injure hands or clothing. Unless sufficient precautions are taken, the bottles may be broken either by jarring in running in or running out or by the high pressures at great depths.

Descriptions of the acid-bottle method have been published by Peele, Hall and Row, Smith, and others.[1]

2. *Briggs' electrical method.*—Professor Henry Briggs, of Edinburgh, invented an electrical method of surveying bore holes. A small vessel containing a highly resistant liquid is lowered in the hole and a similar device is on the ground, the two being connected by insulated wires. At the end of a pendulum, a needle, included in the electric circuiting, is free to swing in the liquid in the lower instrument. In each vessel are four electrodes, marked N, E, S, and W. The orientation of the lower vessel is kept constant, according to the inventor, due to the fact that it is attached to the drill rods which are oriented at the surface. According to the principle of the Wheatstone bridge, variations in the resistance ratios between the needle and the four electrodes in the lower instrument, due to shifting position of the needle when the pendulum swings off center, as in an inclined hole, can be duplicated in the upper instrument by shifting a needle, connected to the circuit, in the liquid in this upper instrument until zero indications are obtained by the recording device. This device may be a galvanometer where direct current is used, or a telephone receiver where alternating current is used.

The advantage of this instrument lies in the fact that it will give continuous readings of angular deviation of the hole from the vertical. Its disadvantages are the necessity for insulated conductors in the hole

[1]Robert Peele, *Handbook for Mining Engineers* (1918), pp. 369-70. O. Hall and V. P. Row, "Wedging Diamond-Drill Holes," *Trans. Amer. Inst. Min. Eng.*, Vol. 63 (1920), pp. 413-20. E. Smith, "Crookedness of Deep Holes Determined by Acid-Bottle Method," *Natl. Petrol. News* (July 21, 1926), p. 50-A.

and, for azimuth readings, the use of an oriented string of rods (see p. 1151).

3. *Use of electric lights.*—In Wyoming, in cable-tool holes, the pracice of suspending electric lights every 50 feet of depth, down to 400 or 500 feet, has resulted in doing away with much of the trouble formerly experienced with the tendency of the holes to go crooked. If the hole is off plumb, as indicated by the light, it must be plugged back to straightness and redrilled. The operators have learned that, if the hole is made absolutely vertical to 500 feet, and the conductor is vertical, there is very little chance that it will deviate much as it is drilled deeper.[1]

4. *The Maas compass.*—An instrument which has long been employed in surveying diamond-drill holes, chiefly in mining districts, is the Maas compass, invented by E. E. White and George Maas.[2] It consists of a small magnetic needle swinging on a pivot attached beneath a small cork. This cork is floated in hot liquid gelatin in a bottle which is lowered in the well in a brass case screwed to a joint or two of brass pipe. The brass tubing can be screwed to the lower end of a full string of steel rods, or it can be let down by a cable.[3] When lowered to the desired depth, the apparatus is allowed to hang stationary long enough for the gelatin to harden, thus setting the compass needle. The attitude of the surface of the gelatin may give an approximate idea of the angle of deviation, and the compass needle shows the direction. If preferred, the acid bottle may be used in combination with the Maas compass.

5. *MacGeorge's method.*—MacGeorge's gelatin method includes the Maas compass in one bottle and a plummet in a second bottle. Both the needle and the plummet are suspended in gelatin.[4]

6. *Oehman's apparatus.*—A more pretentious affair was invented by Oehman.[5] It was widely used in South Africa. It includes a battery,

[1]Personal communications from Ray O. Armstrong and Fred E. Wood.

[2]References on the Maas compass are:
Robert Peele, *op. cit.*, p. 370.
E. E. White, "Surveying and Sampling Diamond Drill Holes," *Trans. Amer. Inst. Min. Eng.*, Vol. 44 (1912), pp. 69-90.
O. Hall and V. P. Row, *op. cit.*, p. 413.

[3]Experiments have proved that such a compass is not affected by steel pipe or cable 10 feet above the magnetic needle. See John I. Hoffman, "Recent Practice in Diamond Drilling and Borehole Surveying," *op. cit.*, p. 494.

[4]Robert Peele, *op. cit.*, p. 370.

[5]Robert Peele, *op. cit.*, p. 371.
J. I. Hoffman, *op. cit.*, p. 483.

a clock, and photographic apparatus. The clock, at a fixed time, completes an electric circuit which turns on an electric light and photographs the position of a plumb-bob and compass needle. Pin pricks mark the orientation of the photographs.

7. *Oriented drill-stem methods.*—In 1873, Oswald J. Heinrich[1] suggested that oriented cores might be secured, in diamond drilling, by using a flat rope which, he said, "would not twist." This is perhaps the first application of a suspended "string," oriented at the surface with the object of determining orientations at depth in a hole. He recommended hoisting carefully and noting the orientation of the core barrel on arrival at the surface. He was probably over-optimistic in his assumption that the flat rope would not twist.

Many years later a method for orienting drill rods was proposed by John Deacon, of Michigan, for use in diamond drill holes, where magnetic rocks were known to be present in the formations. The rods to be run in the hole were first laid out on the ground and screwed tightly together. The joints were then marked where they met, on top of the pipe. Next, the stem was unscrewed at every second joint and was built up again and run into the hole in just the same order, the marks being watched with care, as the couples were screwed up. At the lower end of the stem was attached a joint of pipe containing an acid bottle. The statement is made that when the hole was straight the results were good, but if the hole was deep and crooked, the results might not always be satisfactory. In surveying the hole in this way, the pipe was raised and lowered a few feet several times to take out any possible twist.[2]

The most recent application of the oriented drill-stem method is that invented by Alexander Anderson. It has been widely used by companies in California during the last three years. Just what the internal mechanism of his apparatus is few people know. We have been told that it contains one pendulum or two. The position of the pendulums is said to be recorded by photograph. The apparatus including the pendulums, photographic equipment, and timing and actuating devices is all contained in a water-tight casing which is constructed to be run into the well on the end of a string of drill pipe or tubing. The direction of inclination of the hole is determined by careful surveying of the drill stem or tubing at the mouth of the well, both in the lowering and, for a check, in the lifting of the pipe. To quote from Anderson,[3]

[1]"The Diamond Drill for Deep Boring, Compared with Other Systems of Boring," *Trans. Amer. Inst. Min. Eng.*, Vol. 2, pp. 241-63.

[2]E. E. White, *op. cit.*

[3]Alexander Anderson, "Notes on Underground Surveys of Oil Wells," read at New York meeting of *Amer. Inst. Min. Met. Eng.* (February, 1928).

With the standard apparatus, 88 consecutive readings for inclination and direction of inclination may be taken during one lowering into the well. One reading is generally taken after each stand of pipe is lowered, or say, about 12 readings per thousand feet of hole. Usually 12 readings per hour are taken in a well.

Experiments with an oriented drill stem were tried in Texas, using acid bottles placed in the upset of the tool joint at every fifth fourble. The joints were screwed tight and the lower end plugged with babbitt metal to keep out water and mud. Although the drill stem was built up as rapidly as possible, two hours were consumed in running in to a depth of 3,800 feet. After all bottles were in place, the stem was allowed to stand for four hours. In breaking out the drill stem, a target, marked off in degrees, was attached to the upper end of each fourble, close to the derrick floor. This was accurately surveyed, the stem was then hoisted, and the same target was again surveyed to correct for lean and rotation, at the fourble board, before unscrewing. At the same time another target, which was attached to the upper part of the fourble previously hoisted, was lowered and fastened to the next fourble at the derrick floor. The position of each bottle was accurately determined in relation to the drill stem.

In the Ceptura field in Roumania a very similar method has been tried with some success.[1]

8. *Martienssen's method.*[2]—An instrument used by O. Martienssen in Germany consists of two pendulums pivoted at right angles to each other, recording apparatus for each pendulum, a gyroscopic compass, and electrical equipment employed in actuating the recording device, driving the gyroscope, and turning the metal housing in which all these contrivances are contained. Orientation is governed by the gyroscope according to the well known principle of Foucault. The inner housing is enclosed in a strong water-tight outer casing. The turning of the inner housing is controlled electrically by the gyroscopic compass, being so designed that the enclosed pendulums, fixed with respect to the housing, are always oriented to swing in east-west and north-south planes. The instrument is lowered by cable. Insulated conductors, incorporated in the cable, carry the electric current from the ground surface to the apparatus. In actual use, the instrument is slowly lowered, with the gyroscope rotating and thereby keeping the pendulums always oriented. At every 10 feet (or any other desired interval) a telegraph

[1]Personal communication from H. H. Hill.

[2]Described by F. G. D. Muller in "Much Trouble Caused by Crooked Holes," *Oil Weekly* (April 19, 1924), p. 27.

key is depressed by the operator, thus causing an armature to press a fine needle into the record paper associated with each pendulum.

9. *Rieber's method.*—Frank Rieber, of San Francisco, has improved upon a device built by G. D. Hanna, who in 1926 conceived the idea of using the inertia of a heavy mass, mounted inside the drill stem, for controlling the unlocking and re-locking of a compass and a plumb-bob. In Rieber's instrument there is a pool of mercury in a steel case, and in this mercury is a four-bladed steel paddle, its shaft extending up and outside of the case. When the drill stem is rotated, the paddle starts the mercury whirling, and when the drill stem is stopped, the mercury continues to whirl for some time. Through an ingenious mechanism, which utilizes the effect of the reversed rotation of the retarded drill stem, provided the mercury acquires sufficient speed, a train of clockwork is tripped into action, and this in turn releases the compass needle and the plumb bob, each of which, after coming to rest, automatically punches its position on an aluminum disc. A third mark registers the position of the disc relative to the case and drill stem. Thus a record is obtained of the direction and angle of inclination of the hole.

For each reading a new disc is mechanically brought into position, the old one being removed to a receiving chamber.

DEFECTS AND LIMITATIONS IN METHODS OF SURVEYING HOLES

It may be worth while to mention here some of the more obvious criticisms which may be made of the methods of surveying holes. In some cases the question concerns merely limits of accuracy, although in other cases more serious difficulties may be present. For instance, the small angular errors which may be due to the particular position of the surveying instrument in the hole, or which may be due to capillarity in the acid-bottle method, are not important, for it is doubtful whether the exact angle of deviation of the hole from the vertical, to an accuracy of less than, let us say, 1° or 1½°, is generally possible of attainment.

On the other hand, the objection raised against the magnetic compass, that it is subject to irregular deflection in strata containing magnetite or other magnetic substances, is reasonable. However, this objection has been largely overruled by experience. In mining regions where there is no magnetic ore, numerous records obtained by the Maas compass have been proved to be essentially correct by subsequent mine excavations. There are few occurrences of magnetic substances in sufficient quantity in regions where oil is produced to have any noticeable effect on the needle. Such effects would be local in any event and would

probably be detected without difficulty because of their irregularity compared with the majority of the readings made in the hole. To reduce the chance of mistakes as far as possible, readings by the magnetic compass may be made at two or three points a few feet apart, at each selected depth of observation.

An important objection which has always been raised against the use of any instrument having a magnetic needle lies in the fact that the needle may be affected by the iron pipe in cased holes. However, according to some recent experiments, we are told that in some cases the magnetism in a string of pipe may be concentrated at the ends of the string. That such is always the case seems doubtful, but remains to be demonstrated.

To many engineers the idea that a long string of pipe, suspended by its upper end, will always maintain a constant orientation throughout its length, as it is built up joint by joint, at the surface of the ground and lowered into a hole, is difficult to conceive. The fact that the threading is all in one direction and the fact that the iron or steel of which the pipe is made can not be quite homogeneous in character, lead us to believe that, as more and more weight is added by building up the string, unequal strains are induced, which will ordinarily result in a net twist of the lower end of the pipe, either in a clockwise or a counter-clockwise direction, as the case may be.

This is one suggestion. Another along the same line is that, due to the bent shape induced on a string of pipe suspended in a crooked hole, and also due to friction against the walls of such a hole—in each instance more particularly where the curvature of the hole is not all in one vertical plane—the lower end of such a string of pipe is not likely to maintain its original orientation with increasing depth.

Very few tests have been undertaken to demonstrate whether these suggestions are valid. We have heard of one case in Germany where, out of eight measurements made by an oriented string of pipe to a depth of less than 1,000 feet, six were eventually proved to be correct and two were shown to be in error because of the twisting of the pipe. Other tests have been made, by the use of acid bottles placed in a drill stem, to demonstrate that the stem is rigid. Thus, the bottles, when withdrawn, showed that 2,600 feet of drill stem had rotated throughout its length as many degrees as the angle through which it was turned on the derrick floor; but this in no way proved that the lower end had not acquired a twist in going into the hole, a twist which would disappear in coming out of the hole, and therefore a twist which could not be measured from any observations at the surface.

Is not this a problem which ought to be solved? We have recommended making a study of the behavior of a string of pipe suspended in a vertical mine shaft.[1] We would now suggest further—and this applies to any instruments intended for surveying both the direction and angle of inclination of holes—that wherever holes run together, efforts be made to secure the privilege of surveying and checking the results in both holes. These surveys ought to show intersection of the holes.

As regards the gyroscope, it has its defects which can be explained only by a physicist in terms beyond our ken. One important objection is that it is extremely delicate, and a second lies in its complexity and high cost of manufacture.

METHODS OF TAKING ORIENTED CORES

Several methods have been devised for taking oriented cores. One of these is as follows. A small rat-hole is drilled at the bottom of the larger hole and an instrument constructed to register angle and direction of inclination is firmly placed in the rat-hole. After a sufficient time has elapsed, a large core barrel is run into the hole, and a core is secured by cutting round the instrument. The core and the instrument are then withdrawn together for study.

In California, George A. Macready has invented a core barrel equipped with a plumb bob, magnetic compass, and photographic apparatus.

In conjunction with Martienssen's gyroscopic apparatus, he has an instrument for marking the bottom of the hole in such a way that, when a core is subsequently taken, its position can be determined relative to the instrument and therefore relative to compass directions and the vertical.

Rieber's apparatus can also be used for determining the orientation of cores.

CAUSES OF THE CROOKEDNESS OF HOLES

The causes of the deviation of holes from their desired course may be classified as geological and mechanical. The geological causes, however, are unavoidable. They are conditions which cannot be altered, but which demand recognition, for they can be overcome only by proper methods of drilling.

Geological causes.—Among the geological conditions which may cause a hole to deviate from the vertical are:

1. The presence of "boulders" or concretions which, if encountered at an angle, tend to deflect the bit.

[1] "The Problem of Crooked Holes," *Oil Weekly* (August 31, 1928), p. 34.

2. The dip of the bedding, particularly if the strata consist of alternating hard and soft layers.

3. The presence of fissures, faults, or veins, which offer either considerably more resistance or considerably less resistance to penetration by the bit than the rocks in which they occur.

4. The presence of caverns or other open spaces.

5. Caving and heaving of rock materials when exposed during drilling.

Mechanical causes.—The following are some of the mechanical causes for the crookedness of holes:[1]

1. Starting the hole off the vertical.
2. Using poor material.
3. Use of bit not best adapted to the conditions.
4. Use of bit with too much cutting clearance.
5. Spudding the bit.
6. Use of too small a drill stem.
7. Bent or corkscrew form of drill stem, with resulting rubbing of sides of holes.
8. Too much clearance between drill stem and hole.
9. Sidetracking.
10. Use of mud of wrong consistency.
11. Use of big pumps.
12. Coring or rat-holing, or otherwise reducing hole, where sufficient precautions are not taken to center the small hole and keep it straight.
13. Application of too much pressure on the bit.

Most of these causes, as stated, are self-explanatory. A few of them deserve a little discussion. Practically all those who have given much thought to the problem of crooked holes are agreed that one of the principal causes is excessive pressure on the bit. In other words, not enough of the weight of the drill stem is lifted off the cutting surface of the bit. As a consequence the drill stem may be bent, especially when the diameter of the hole is considerably more than the diameter of the drill pipe, and where, for one reason or another, the hole has become abnormally enlarged. Drillers with whom we have talked are of the opinion that holes—we are speaking now chiefly of rotary holes—begin to deviate from the vertical between 500 and 1,000 feet below the surface. Some of

[1]E. J. McKee, "Some Causes and Effects of Crooked Holes," *Oil Weekly* (November 23, 1928), p. 60.

them claim as high a level as 250 or 300 feet. Why is this? Is it because the weight of 500 or 1,000 feet of drill stem is perhaps as much weight as should be applied to the bit while in operation? With ordinary 25-pound 6-inch pipe, this weight, for a complete drill stem and 11-inch bit, in a hole 1,000 feet deep, would be about 32,900 pounds, after deducting for buoyancy due to the mud, assumed to weigh 10 pounds per gallon. For 22-pound 6-inch drill stem with an 8-inch bit, this figure would be about 30,400 pounds. However, we know that much greater weights are used.[1] R. S. Cartwright[2] suggested 38,000 pounds as the most efficient weight for all formations. Possibly this will be proved to be too great, when we have learned more as to what weights are most satisfactory.

Another potent factor in causing holes to turn out of line is the hydraulicking action of the mud where it is forced out of the bit. Many drillers admit that, in soft formations, the "drilling" amounts to little more than jetting the hole down. The force of this jetting action as it comes out of the small holes in the bit must be tremendous where 400 or more gallons are being pumped down every minute. By this hydraulicking, undoubtedly wide openings are sometimes cut, instead of a clean cylindrical hole of uniform diameter, and these openings afford ample opportunity for the drill stem, under pressure, to bend out of the axis of the hole. Furthermore, the jetting, or hydraulicking, may wash out the bottom of the hole off center and so lead the bit astray.

We believe that these two factors of excessive weight on the bit and excessive speed of circulation are most important in causing the crookedness of holes. Most of the other factors are contributary, but under properly controlled pressure and circulation and with adequate equipment, these other factors can be largely overcome.

REMEDIES FOR THE DEVIATION OF HOLES

Wherever possible the geologist should, of course, warn the driller of any known contacts between formations of very different resistances to the action of the bit, and of any known faults, or other similar features. But the best warning is, expect these features anywhere. Drill in a manner best suited to overcome these unknown conditions whenever they occur.

[1] R. Van A. Mills discusses this matter on p. 131 of his excellent paper, "Crooked Holes Discussed by Engineers," *Oil and Gas Jour.* (August 23, 1928), p. 30.

[2] "Rotary Drilling Problems," *Amer. Inst. Min. Met. Eng. Tech. Pub. 145* (October, 1928). See also same paper published in *Oil Weekly* (November 2, 1928), p. 41. Cartwright gives a table showing suitable weights to be applied in drilling rocks of different kinds. In several catalogs, proper weights are suggested by the manufacturers for special types of bits.

Since geological conditions which may favor the deviation of holes can neither be altered nor predicted, except in a general way, the opportunity for correcting the defect rests almost entirely with the driller. If the driller or the drilling contractor is told that he must reach the pay sand, or any specified depth, in the shortest possible time, then those who gave him this order are to blame. First, therefore, those who are responsible for rushing the drilling must be disillusioned. They must learn that less speed with a more perfect hole is, in the long run, most economical.

If excessive pressure on the bit and hydraulicking are the principal mechanical causes of crooked holes, we must make serious efforts to improve these conditions. Weight indicators should be installed. Probably improved indicators can be made, and more satisfactory bits can be designed. Most important, methods of automatically controlling the pressure on the bit should be invented. In any event these phases of drilling should be carefully and intensively studied.

Clearance of the drill stem in the hole.—To reduce the risk occasioned by too much clearance between the drill stem and the hole (whether open or cased), several contrivances have been used or suggested. Rubber collars may be placed at intervals, generally on every joint or every other joint, on the drill stem when it is rotating inside casing. They were supplied to protect the drill collars, but they also serve to center the pipe. Some success is claimed by drillers who have placed a roller reamer just above the bit and another one or two joints higher up in the drill stem. In reducing a hole, a diamond-point bit is sometimes used to drill a conical bottom to the hole, so that the smaller bit will start in a central position. However, in rat-holing and coring, precautions are seldom taken to center the small hole. Frequently the drill stem is made up with several joints of the next larger size of pipe at the lower end of the string. None of these methods is entirely satisfactory for all conditions and most of them lose their efficacy if too much pressure is applied in the drilling.

Limitation of permissible angle of deviation in drilling.—The most concerted effort to remedy the drilling of crooked holes has been made during the last year in the Seminole field in Oklahoma. Here so many holes wandered so far from the vertical that the operators simply had to take notice. And they have done so with effect. The contractors admit that they *can* drill straighter holes, but they say it costs them about $2,500 more per 4,000-foot well. Some contracts now require the plugging back and redrilling of holes which are found to deviate more than

10° or 15° from the vertical. For example, the following is quoted from the rotary-drilling contract now being used by one company (the first party) with its drilling contractors (second party):

> First party shall have the right at any time it may desire to make a survey of the well to determine the condition of the hole, at the risk and expense of second party. Such survey shall be made by such method as first party may desire. When such test is made and the hole is found to deviate as much as fifteen degrees from perpendicular, first party may require second party to redrill said hole at second party's expense. If after completion of said well it is surveyed and found to exceed fifteen degrees variation from perpenducular, it shall be optional with first party whether or not it accepts the hole, and in case of non-acceptance first party shall not be liable for any expense connected with drilling said well and will be under no obligation to second party.

The question has arisen as to whether 10° or 15° or some other angle is suitable as a maximum permissible limit. Let us glance at Figure 33. In the left diagram the well spacing is 660 feet, and in the diagram on the right it is 300 feet. On the basis of a permissible maximum limit of 10° for the deviation of the hole from the vertical, and assuming that just this angle is maintained all the way down from the surface, a hole 1,000 feet deep would be 174 feet out of plumb at the bottom, a 2,000-foot well would be 347 feet off; a 3,000-foot well, 521 feet off; a 4,000-foot well, 695 feet off; and a 5,000-foot well would be 869 feet off the vertical. Obviously, a 10°-limit would be too great for a 2,000-foot hole, if the hole deviated 10° all the way from the surface. It would be too great for a 3,000-foot well assumed to have been drilled vertical to 1,000 feet and then to have deviated 10° from the vertical to the bottom. And so on.

To be sure, this is not quite the way in which holes become crooked, but the diagram proves that 10° is too great a limit to allow for a 4,000-foot well, unless this angle of deviation commences below a depth of 2,000 feet.

For comparison, lines have been drawn to show the approximate angles, subtended at different depths by a horizontal offset of 330 feet in Figure 33, *A*, and 150 feet in Figure 33, *B*.

It is questionable whether, in the drilling, any angle of deviation can be safely permitted much greater than the angle which, at any given depth, would eventually displace the bottom of the hole more than half the offset distance[1] away from the vertical through the mouth of the hole. The fact that crooked holes do not turn off sharply and then maintain a straight inclined course, but instead bend more or less gradually and drift in a horizontal sense, means that the conditions illustrated in Figure

[1]The distance between offset wells in the particular field.

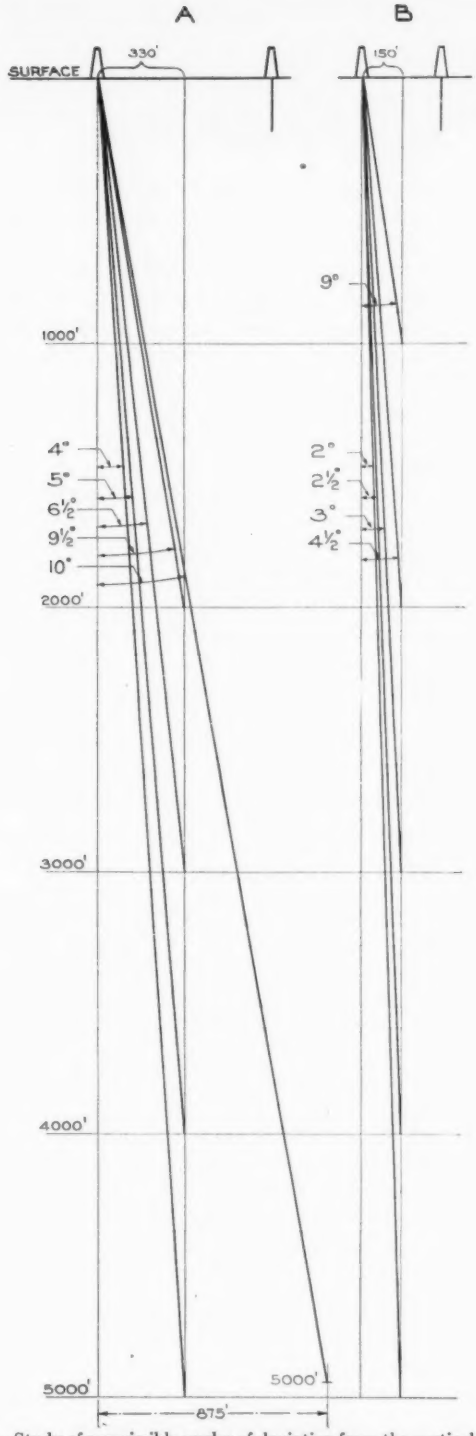


FIG. 33.—Study of permissible angles of deviation from the vertical in wells drilled as deep as 5,000 feet. *A* shows two wells 660 feet apart, and *B*, two wells 300 feet apart, on the surface. It is assumed that all the deviation is in the same vertical plane, and that, in each case, the angle of deviation is constant between the given depths. These assumptions give figures which are extreme, probably at least 25 per cent greater than under ordinary conditions of drilling.

33 are extreme. Consequently, if these conditions are taken as a basis for estimate, as we have done, a little more latitude in vertical angular deviation can be allowed without danger.

Advantages of the oriented whipstock.—Where a hole is found to deviate as much as the permissible angle, according to the clause previously quoted from a drilling contract form, some of the Oklahoma operators have required that the hole be plugged back to the part known to be vertical and then that it be redrilled. This was done in the well shown in Figure 4. This method has met with some success; but it is rather haphazard and unscientific, for the second hole is as likely to be crooked as the first, starting as it does against a hard cement plug. A much more practical plan would be to set a properly oriented wedge or whipstock, at the bottom of the crooked hole, and then continue drilling, in this manner saving the cost of plugging back and redrilling and saving the risk of drilling the second hole crooked.

On the assumption that it is possible to measure the direction and angle of deviation at any point in a crooked hole, there is no mechanical reason why a whipstock can not be set in any azimuth desired and at any depth desired, provided the right kind of equipment is available. Oriented wedges for correcting deflection have long been known and used in diamond drilling. A method conceived by a Mr. Welldon, and improved and used in South Africa by A. Payne Gallwey, has been described by John I. Hoffman.[1] In Germany, O. Martienssen has also devised a method of wedging holes back toward the required position.

CONCLUSION

In conclusion, we would emphasize this fact, that whether the immediate effects of crooked holes are excess of footage drilled, or twist-offs, fishing jobs, and other adversities in drilling, or wear and loss in pumping and other producing operations, or misinterpretation of geological data, or erroneous results in production engineering problems, the final consequence is *financial loss*. And the difficulties and the losses will be greater, the deeper we drill for oil.

It is true that some holes have been shown by proper surveying to be vertical. Only two days ago we learned of a well drilled in the Seminole district in Oklahoma to a depth of more than 5,000 feet, and drilled vertical all the way. This is a fine achievement. Its particular value is that it is proof that deep straight holes can be drilled. But at present such holes are rare. We must learn how to drill vertical and how

[1] John I. Hoffman, *op. cit.*, pp. 486-87.

best to bring holes back into their proper position when they are not vertical and we must improve the accuracy of our subsurface information by securing correct surveys of the underground courses of holes and by establishing the correct orientation of cores from these holes.

Once again, as so often in the past, the industry is forced to admit that, in the long run, careful scientific methods, rather than hit-or-miss untechnical methods, are most economical, and therefore most practical.

BIBLIOGRAPHY[1]

1872 Eckley B. Coxe, "A New Method of Sinking Shafts," *Trans. Amer. Inst. Min. Eng.*, Vol. 1, pp. 261-76.

1873 Oswald J. Heinrich, "The Diamond Drill for Deep Boring, Compared with Other Systems of Boring," *Trans. Amer. Inst. Min. Eng.*, Vol. 2, pp. 241-63.

1873 W. Wybergh, "On Diamond Drilling in the Transvaal," *Trans. Inst. Min. and Met.* (London), Vol. 6, pp. 164-74.

1905 H. F. Marriott, "Deep Bore-Hole Surveying," *Trans. Inst. Min. and Met.* (London), Vol. 14, pp. 255-70.

1907 A. Zboril, "The Deflection of Bore-Holes in Diamond Drilling on the Rand," *Jour. S. African Assoc. Eng.* (Mar.).

1907 "Note on Deflection of Bore Holes," *Chem. Min. and Met. Soc.*, Vol. 7, p. 380.

1907 Joseph Kitchin, "The Deviation of Rand Bore-Holes from the Vertical," *Trans. Inst. Min. and Met.* (London), Vol. 17, pp. 87-136.

1909 Jean Florin, "Compass and Camera Survey." *Eng. and Min. Jour.*, Vol. 87, p. 854.

1910 E. E. White, "Control of Curvature," *Eng. and Min. Jour.*, Vol. 90, pp. 546-47.

1912 E. E. White, "Surveying and Sampling Diamond-Drill Holes," *Trans. Amer. Inst. Min. Eng.*, Vol. 44, pp. 69-90.

1912 John I. Hoffman, "Recent Practice in Diamond Drilling and Borehole Surveying," *Bull. Inst. Min. and Met.* (London, Apr. 18).

1914 E. E. White, "Dip of Beds from Drill Cores," *Eng. and Min. Jour.* (Sept. 19).

1918 Robert Peele, "Deviation of Boreholes and Methods of Survey," *Mining Engineers' Handbook*, pp. 369-76. (Ed. 1918).

1920 T. W. Chalmers, *The Gyroscopic Compass*, Van Nostrand, New York.

1920 O. Hall and V. P. Row, "Wedging Diamond-Drill Holes," *Trans. Amer. Inst. Min. Eng.*, Vol. 63, pp. 413-20.

[1]Many of the following references are from H. B. Goodrich's private bibliography.

1920 F. A. Edson, "Use of Diamond Drill in Oil Fields," *Oil and Gas Jour.* (Dec. 24).

1922 "Trade Notes Spiral Stem," *Oil Weekly* (Dec. 23), p. 91.

1923 H. L. Terwilliger, Discussion of paper by, on "Rock Drills and Drill Steel." *Eng. and Min. Journal-Press* (Dec. 29, 1923), p. 1128.

1923 Sven Lundberg, "Bore Hole Surveying by the Kiruna Method," *Eng. and Min. Jour.* (Feb. 8).

1923 A. G. Wolf, "Measuring Depth Accurately in Rotary Drilling," *Eng. and Min. Jour.* (Dec. 29).

1924 F. G. D. Muller, "Much Trouble Caused by Crooked Holes," *Oil Weekly* (Apr. 19, 1924), p. 27.

1924 Victor Svimonoff, describes surveying of wells (in German), *Petroleum*, Vol. 20, H 14 (May), pp. 595-603.

1924 "Magnetism Affecting Drilling." *Oil and Gas Jour.* (Feb. 7), p. 124.

1925 E. L. Estabrook, "An Alibi for Geologists," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, p. 1295.

1925 "Oil Well Survey Machines Record Important Data in Wells," *Oil Age* (August).

1925 Victor Svimonoff, "Method of Checking Verticality of Oil Wells," *Petroleum World* (London, Sept.), p. 382.

1926 "The Owens Bore Hole Alignment Indicator," *Engineering* (Jan. 15).

1926 F. M. Smith, "Surveying Oil Wells with Anderson Apparatus," *Eng. and Min. Jour. Press* (Feb. 6), pp. 241-46.

1926 "Two California Companies Discover They are Drilling in Same Hole," *Oil and Gas Jour.* (Apr. 29), p. 181.

1926 L. E. Smith, "Crookedness of Deep Holes Determined by Acid-Bottle Method," *Natl. Petroleum News* (July 21), p. 50-A.

1926 F. S. Hudson and N. L. Taliaferro, "An Interesting Example of a Survey of a Deep Bore Hole," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, pp. 775-85.

1926 List of World's Seven Deepest Wells, *Oil Age* (Aug.), p. 13.

1926 Alexander Anderson, "Underground Survey of World's Deepest Well Shows Deviation and Direction of Hole," *Oil Age* (Sept.); *Oil and Gas Jour.* (Sept. 9), p. 29, and *Petroleum World* (Sept.).

1926 F. M. Smith, "Lateral Drift of Holes in Deep Drilling Shown by New Apparatus," *Oil and Gas Jour.* (Sept. 2), pp. 120, 122-23, 127.

1926 Describing Russian Practice of Straightening Holes, *Petroleum World*, Vol. 22, No. 300 (Sept.)

1926 H. B. Goodrich, "Crooked Hole Problem Being Studied," *Oil and Gas Jour.* (Nov. 15, 1928), p. 38.

1927 "Danger of Crooked Holes," Notes on article by R. R. Boyd, *Oil Field Eng.* (May), p. 49.

1927 "The Wanderings of an Oil Well," *Scientific American* (July), pp. 46-47.

1927 "Migration of Rotary Drill Holes," *Standard Oil Bulletin* (Sept., 1927), pp. 12, 13, 16.

1927 J. L. Dwyer, "Little River Wells Run Together" (Dec. 29), p. 78.

1928 "Rough Handling May Ruin Best Pipe," *Oil and Gas Jour.* (June 7), p. 135.

1928 J. French Robinson and J. A. Montgomery, "Deep Drilling in the Appalachian Field with Cable Tools," *Oil Field Engineering* (Aug. 1), pp. 26-31.

1928 R. Van A. Mills, "Crooked Hole Discussed by Engineers," *Oil and Gas Jour.* (Aug. 23), p. 30.

1928 J. L. Dwyer, "Crooked Holes Cost Industry Vast Sum," *Oil and Gas Jour.* (Aug. 23), p. 29.

1928 F. H. Lahee, "The Problem of Crooked Holes," *Oil Weekly* (Aug. 31), p. 34.

1928 "The Crooked Hole Problem" discussed by W. R. Cummings, Hollis Porter, and R. Van A. Mills, *Oil and Gas Jour.* (Sept. 13), p. 41.

1928 "Reamers and Controlled Feed Tend to Make Straight Hole," *Oil Weekly* (Sept. 28), p. 34.

1928 R. S. Cartwright, "Rotary Drilling Problem," *Amer. Inst. Min. Met. Eng. Tech. Paper 145* (Oct.); also *Oil Weekly* (Nov. 2), p. 41; also *Amer. Inst. Min. Met. Eng. Petrol. Dev. and Tech., 1928-29* (1929). pp. 9-29.

1928 K. C. Sclater and V. R. Stephenson, "Method of Obtaining Bottom Hole Data," *Oil and Gas Jour.* (Oct. 25), p. 114; also *Natl. Petrol. News* (Oct. 31), p. 59.

1928 H. B. Goodrich, "Crooked Hole Problem Being Studied," *Oil and Gas Jour.* (Nov. 15), p. 38 (see under 1926).

1928 H. B. Goodrich, "Importance of Crooked Hole Problem," *Oil and Gas Jour.* (Nov. 15), p. 165.

1928 W. R. Martin, "Crooked Hole Problem Further Discussed," *Oil and Gas Jour.* (Nov. 15), p. 165.

1928 E. J. McKee, "Some Causes and Effects of Crooked Holes," *Oil Weekly* (Nov. 23), p. 60; also *Oil and Gas Jour.* (Nov. 22), p. 51.

1928 T. F. Smiley, "Committee Will Study Crooked Hole," *Oil and Gas Jour.* (Nov. 22), p. 39.

1928 J. T. Hayward, "Torque Indicator Problem," *Oil and Gas Jour.* (Nov. 29), p. 30.

1928 L. J. Black, "Discussion of Crooked Hole Problem," *Oil and Gas Jour.* (Nov. 29), p. 30.

1928 "Blames Too Much Speed for Crooked Holes," *Natl. Petrol. News* (Nov. 14), p. 30.

1928 "Acid Tests Reveal Crooked Holes in Winkler County," *C. D. Lockwood's Texas Oil Rept.* (Fort Worth) (Dec. 12 and Dec. 13).

1928 A. Beeby Thompson, "Oil Field Practice in 1927," *Jour. Inst. Petrol. Tech.* (London), Vol. 14 (Dec.), pp. 841-53.

1928 G. Heseldin, "Drilling and Production Methods in the Greater Seminole Field, Oklahoma, U. S. A." *Jour. Inst. Petr. Tech.* (London), Vol. 14 (Dec.), pp. 783-824.

1928 Martin Van Couvering, "Taking the Crooks out of the Drill-Hole," *Oil Bull.* (Dec.), p. 1259.

1929 O. B. Goldman, "The Question of Torque," *Oil and Gas Jour.* (Jan. 24), p. 34.

1929 O. B. Goldman, "Modern Well Drilling Is Straightening out Crooked Hole and Twist-off Evils," *Petrol. World* (Los Angeles). Vol. 14 (Jan.), pp. 46-47, 121.

1929 Frank Redick, "Crooked Holes," *Oil and Gas Jour.* (Jan. 24), p. 34.

1929 Martin Van Couvering, "Courses of Drill Holes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (Feb.), pp. 109-16.

1929 Alexander Anderson, "Notes on Underground Surveys of Oil Wells," Read before New York meeting of *Amer. Inst. Min. Met. Eng.*, February.

CONTROL AND ADJUSTMENT OF SURVEYS WITH THE MAGNETOMETER OR THE TORSION BALANCE[1]

DONALD C. BARTON[2]
Houston, Texas

ABSTRACT

Some degree of residual error is present in practically every observation with a magnetometer or a torsion balance. Errors of some types can be avoided, or greatly reduced, by careful technique of observation. Other errors can be reduced by the application of corrections, but in general some residual error will persist. Errors in isolated or widely separated observations or, in general, in single lines of stations, are not detectable or at least are not strikingly evident. But if the stations are so placed that there are closed circuits of observations, the errors generally produce more or less discordance.

Adjustment of mutually discordant systems, or sets of stations, is necessary for their satisfactory use for all but the rougher interpretation. The adjustment gives a probable value for each station with due regard to all of the observations more or less mutually affecting it. Various types of control and adjustment are in use. The method of least-square adjustment is the most accurate of the methods of adjustment, but requires at least moderate mathematical skill and is distinctly tedious. But for the degree of accuracy in commercial geophysical work in oil geology, certain approximate schemes of least-square adjustment can be cast in simple tabular forms, which are easy to use and which require no knowledge of higher mathematics.

ERRORS IN MAGNETOMETER OBSERVATIONS

The errors likely to occur in the use of the vertical magnetic variometer of the Schmidt Lloyd or G. P. G. types arise from the following causes.

A. FLUCTUATIONS OF THE MAGNETIC FIELD AROUND THE INSTRUMENT

1. *Normal diurnal fluctuations of the vertical component of the earth's field.*—At the Tucson, Arizona, observatory of the United States Coast and Geodetic Survey, for the years 1917-18, the diurnal fluctuation ranged from -10 to -22γ between 11 A. M. and 2 P. M. to $+4$ to $+12\gamma$ near 6 P. M. in comparison with the mean value.[3]

[1]Read before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, March 15, 1929.

[2]Consulting geologist and geophysicist, Petroleum Building.

[3]D. L. Hazard, "Results of Observations Made at the U. S. Coast and Geodetic Survey Magnetic Observatory near Tucson, Arizona, 1917 and 1918," *U. S. Coast and Geod. Survey Serial 155* (1921).

2. *Magnetic storms.*—During 1917 and 1918 at Tucson, the average of magnetic storms was one day each week. For 22 of these storms, the peaks of the fluctuations above or below the value of the vertical intensity immediately before the storm amounted to:

(−22, +36; −21, +11); (−20, +0; −31, +3); (−36, +15); (−10, +8, −8, +45, −8, +30); (−50, +0); (−30, +40); (+7, −23, +2); (−18, +20); (−13, +0); (−4, +0); (−6, +1); (+91, +40); (−8 +22, −12); (−27, +70, +35); (−72, +14, −10); (−12, −22, +20); (+16, −24); (−37, +15, −42; (−12, +28) gammas. The largest variations in a short time were:

−21γ in 1½ hours, −22γ in ½ hour, −35γ in 1¾ hours, +20γ in 1 hour, −18γ in ½ hour, −18γ in ¼ hour, +18γ in 1 hour, −10γ per hour for several hours, −5γ in 5 minutes, +58γ in 2¼ hours, −38γ in 4¾ hours, −10γ in 20 minutes, −22γ in 2 hours, +50γ in 1½ hours, +25γ in 1 hour, −22γ in ¾ hour, +46γ in 1 ⅓ hours, and +22γ in 2 hours. The relative magnitude of these storms was: Class I, four; II, fourteen; III, three; IV, one; where class IV is the most intense and class I the least.

3. *Artificially produced fluctuations.*—Electric currents produce an electromagnetic field, which is superimposed on the earth's magnetic field. High power lines, electric street cars and interurban lines, electric lighting circuits, et cetera, therefore, cause the intensity measured by the magnetometer to be too high or too low, and in general, as the intensity of the electric currents fluctuates rapidly, the intensity of the electromagnetic field fluctuates and a magnetometer within a city or within a field of a high-power line may give a different reading from minute to minute or may not come sufficiently to rest for an observation to be made.

B. CAUSES WITHIN THE INSTRUMENT

1. *Variation of the magnetic moment of the instrument.*—Variation of the temperature of the magnet produces corresponding changes in the magnetic moment of the magnet. Repeated temperature changes and the continual jarring due to transportation cause a gradual loss in the strength of the magnet during use with a partial recovery, however, during rest periods. The correction for the temporary fluctuations by observations of the temperature and the use of a temperature correction coefficient is not entirely satisfactory, as, in practice, the temperature observed may not be the actual temperature of the magnet system and as the temperature coefficient of the instrument may change.

2. *Variation of the gravitational moment of the magnetic balance.*—The center of gravity of the magnetic balance lies below its center of rotation and the theory of the calibration of the instrument is based on the fact that the balance comes to rest when the magnetic moment is balanced by the gravitational moment produced by the rotation of the center of gravity out of the vertical axis of the instrument. The magnetic balance is composed of several parts which can not be welded together and the sensitivity is regulated by a screw. The inevitable slight shifting of the parts and the screw under the inevitable shaking of field use produces a shift of the center of gravity which changes the amount of deflection of the magnetic balance for a given variation of the intensity of the vertical component of the earth's field. As the deflections measured are very small, an extremely small shift of the center of gravity may produce a serious error. Such shifts may take place suddenly between stations or may take place gradually.

3. *Inaccurate levelling.*—If the axis of rotation of the instrument has a slight inclination from the vertical in magnetic meridional plane, the apparent vertical intensity contains a component of the horizontal intensity, which is directly proportional to the angle between the axis of rotation and the vertical. For the vicinity of Tucson, an angle of inclination of the axis of rotation of the instrument of 0.01° in the meridional plane will cause an error of about 2.7 γ.

4. *Damaged or dirty knife edge or rests.*—A magnetometer with a chipped or dulled knife edge or rests is useless and grease or dirt on the knife edge or rests may produce erratic errors in the readings.

5. *Slippage of the magnet on the torsion wire or of the torsion wire in its fastenings in the G. P. G. (torsion wire) type of magnetometer.*—If the fastening nuts are not tightened with very considerable force, there is a tendency for the magnet to slip and become slightly unbalanced on the torsion wire. One end of the torsion wire may begin to work loose and rotate and will then cause a continually increasing error.

C. STATIC IRREGULARITIES OF THE MAGNETIC FIELD SURROUNDING THE MAGNETOMETER

The field affecting the instrument is the vectorial sum of the fields produced by a heterogeneous series of objects, possibly including the observer's belt buckle, small iron junk hidden in the grass, an iron concretion hidden just under the grass roots, and other minor artificial or natural irregularities in which the geologist is not interested, as well as the geologic structure which he hopes to be able to map. Some natural terranes are magnetically homogeneous and others are magnetically

heterogeneous, and in the latter, accurate observation at stations only a few tens of feet apart may show considerable discordance.

D. INACCURACIES IN CALCULATION

ERRORS IN TORSION-BALANCE OBSERVATIONS

Errors likely to occur in the use of the torsion balance arise from the following causes.

1. *Change of the torsion constant of the wire.*—There is a slight change in the torsion constant of the torsion wire with changes of temperature and with fatigue, and in some wires seemingly with age.

2. *Shift of the zero point.*—In varying degrees, torsion wires show a shift of the zero point during observations. The cause of the shift lies largely in the effect of temperature changes, but in part may be due to fatigue. The shift, rather commonly, is in one direction while in use during the day and in the reverse direction while at rest during the night. If the shift is linear during an observation and if five readings in the 120°-method are taken, the effects of the shift fall out in the calculations, but if, as commonly, the shift is irregular, or if only four readings are taken in the 120°-method, an error is introduced which is proportional to the shift.

3. *Irregularities due to air currents within the instrument.*—If the lower part of the instrument is heated or the upper part cooled, air currents may be set up which may cause slight irregularities in the readings. If the instrument is not air tight, air currents may be set up in and out of the instruments by temperature variations and vitiate the observations with that instrument.

4. *Inaccuracy in the determination of the terrane correction.*—In some places, it may be impracticable to get any satisfactory levels for the terrane within 5 meters of the instrument. There is also more likely to be failure to take, carelessness in taking, or faking in connection with the taking of the levels for the terrane correction than in the rest of the work of a station observation.

5. *Irregularities of density in the subsoil near the station.*—Concretions, boulders, a filled-in cellar, a hole, heterogeneous mixtures of sand, gravel, clay, rock, irregular bed rock covered by alluvium, all produce irregularities, which are of very local effect and which for most purposes of the geologist are errors.

6. *Inaccuracies in calculation.*

7. *Inaccuracy in the assumption that the difference in gravity between two stations may be calculated on the basis of the assumption of linear variation of the gradient between the stations.*

MINIMIZATION OF ERRORS

Those errors may be avoided in part or minimized. Magnetic observations should not be taken near high-power lines, or other causes of disturbance which may produce fluctuations of the field. The effects of temperature changes can be minimized by shielding the magnetometer as much as possible from them. The effects caused by shifts of the center of gravity of the balance can be minimized by shielding the magnetometer from shocks and vibration as much as possible. The errors caused by iron in the observer's pocket or belt buckle, or because stations are on railroad tracks, near wire fences, 55,000-barrels tanks, iron junk in the grass, or under low-hanging iron telephone wires can be avoided by using a competent observer with his mind on his work. The temperature effects in the torsion balance can be avoided by using wires, which are relatively insensitive to temperature changes, or can be minimized by shielding the instrument from temperature changes; in the middle of a hot summer day in Texas, it may be preferable to ventilate the shelter rather than keep it air tight; in cold weather it may be advisable to regulate the temperature with a candle or lantern. Errors due to carelessness or faking in taking the levels for the terrane correction can be avoided by using reliable men. Errors due to inaccuracies in calculations can be avoided by having two men do all calculations independently.

Corrections may be applied for some of the errors. The normal diurnal fluctuations and the fluctuations during moderate magnetic storms can be corrected by comparison of the observations with the respectively simultaneous values of a recording magnetometer, but unfortunately, there is no observatory near enough for most of the work in Texas, Louisiana, Arkansas, and Oklahoma; and if the present considerable use of the magnetometer in the Mid-Continent area continues, it would seem worth while for the oil geologists to work for the establishment of perhaps three simple observatories, one in central Texas, one in Oklahoma, and one in the north Louisiana-Arkansas area. The temporary effects of fluctuations in the temperature can be compensated for, in large part, by a temperature correction, and permanent loss in the strength of the magnets can be corrected for by periodic recalibration. In the torsion balance, the rather small change of the torsion constant with temperature changes can be compensated for by a correction, but no satisfactory method of correction for a non-linear shift of the zero point has been devised. The effects of topographic irregularities

at and near the station normally can be compensated for by appropriate corrections.

Some errors, which can not be compensated for by corrections, can be detected and the ill effects of the errors avoided by throwing out the particular observations. Severe magnetic storms and the presence of a fluctuating artificial electromagnetic field can be detected by the quivering of the balance and shift of the position of rest during the taking of a reading. The shift of the zero point of the torsion balance appears in the observations, and if the shift is too great and non-linear, the results of that observation can be thrown out, or, with a visual instrument, the observation can be continued until satisfactory readings are obtained. Single values severely in discordance with the general picture of the survey may be discounted or thrown out by an experienced interpreter.

Some appreciable error remains in practically every field observation with a magnetometer or torsion balance. Consequently, if the difference in the value of magnetism or gravity at two stations is obtained or calculated by different routes, as many values will be obtained for the difference as there were routes used. If there are only two stations in question, the most probable value for the difference is the simple mean of the different values. If the values obtained via the different routes are not of equally probable accuracy, a weighted mean should be used. But if the survey consists of many stations, more advanced methods of obtaining the most probable value for all the stations must be used. Various methods of control and adjustment are usable and vary considerably in their simplicity, tediousness, and accuracy.

ADJUSTMENT OF SURVEYS

ADJUSTMENT OF A CLOSED TRAVERSE

The simplest case for adjustment is a single closed traverse. Any error of closure is distributed linearly back through the traverse. In torsion-balance traverses, the distribution of the error should be weighted and more error thrown in the longer gaps between stations, between stations with reversals of gradient, and in parts where the gradients are large or irregular, and less error in the other parts of the traverse. In magnetometer work, there is a dangerous tendency for inexperienced observers to use a single central bench mark and to run numerous closed traverses from this bench mark without tying them together. Such traverses, if adjusted, may be used singly, but if two or more are used together, anomalies may appear which are due entirely to the failure to tie and adjust the traverses together.

METHODS OF SIMPLE, PROGRESSIVE ADJUSTMENT

The simplest method of control and adjustment of a survey covering a considerable area is to start from some known or assumed bench mark and (*a*) run a closed traverse and adjust it, (*b*) assume all stations on it to be secondary bench marks and run out from any station and check back into any station, (*c*) assume all stations on both traverses to be secondary bench marks and run out from any station on either traverse and check in on any other station, and so on. Any error of closure is distributed linearly back through the new traverse. Considerable danger lies in the use of this method of adjustment, although it is a valid rough first approximation in adjustment to obtain the most probable values for all stations. Although the error of closure in each new traverse is assumed to be due wholly to errors in the new traverse, the error as a matter of fact may lie wholly in the adjusted line between the starting and finishing bench marks, and the error therefore is forced into the new traverse. If the magnetometer traverse is checked into the same secondary bench mark from which it started, there is one chance in three that the adjusted value for that station is too high, and one chance in three that it is too low. All values of the new traverse then will be correspondingly too high or too low. If the secondary bench marks from which a new traverse runs out, and on which it checks in, are not the same, there are two chances out of nine that the values of both bench marks will be either too high or too low and that, therefore, all values on the new traverse will be correspondingly too high or too low.

A simple but more accurate method of control and adjustment is to use a base line instead of a single base bench mark. In magnetometer surveys, a base line can be run by (*a*) choosing the best road traversing the area to be surveyed, (*b*) establishing three or more primary bench-mark stations widely spaced, and (*c*) running and re-running as rapidly as possible between adjacent stations, until some consistent value is obtained for the difference of the values of the two stations. But care must be taken to distribute the times of the various runs during the day so that the effects of the diurnal fluctuation will cancel out. In many surveys, it is advisable to make the base line in the form of a cross. If the area to be covered is very large, it may be advisable to make the base line a fairly large closed traverse, which itself can then be adjusted for any error of closure. After the base line has been established, secondary traverses are run out from one primary bench mark and checked into another. Certain stations on the secondary traverses may be taken with more care than usual and then used as secondary bench marks. Tertiary

traverses are run from these secondary bench marks to primary or secondary bench marks and so on. For each new traverse, any error of closure in checking in on a bench mark on a traverse already adjusted is distributed linearly through the new traverse.

The base line in a torsion-balance survey preferably should not be laid out until the survey is fairly well advanced. The base line should then be placed where the gradients are small and consistent, and should be run by spacing the stations one-fourth as far apart as normal. The closer the stations are spaced, the less the probable error of the base line.

If the stations are scattered rather uniformly throughout the area of a torsion-balance survey, a progressive adjustment may be made outward from some base line or central base station and may be used as a first crude approximation to the most probable adjustment. If in Figure 1, A, B, C, and D are the values of gravity at four stations forming a base line, if E, F, et cetera are the most probable values of gravity for other stations, and if $a, b, c,$ et cetera are the values of ΔG calculated from the observed gradients, then the F can be taken as $\frac{1}{3}[(B + c) + (C + d) + (D + e)]$, E as $\frac{1}{2}[(A + a) + (B + b)]$, G as $\frac{1}{3}[(E + j) + (B + i) + (F + h)]$, H as $\frac{1}{2}[(D + b) + (F + g)]$, K as $\frac{1}{2}[(E + k) + (G + l)]$, L as $\frac{1}{3}[(K + o) + (G + m) + (H + n)]$ and so on through the survey. If there is no base line from which to start, a central group of stations which tell a consistent story and which form a closed circuit with a low error of closure, may be chosen as a set of base stations, and mutually adjusted and then the adjustment carried progressively out in

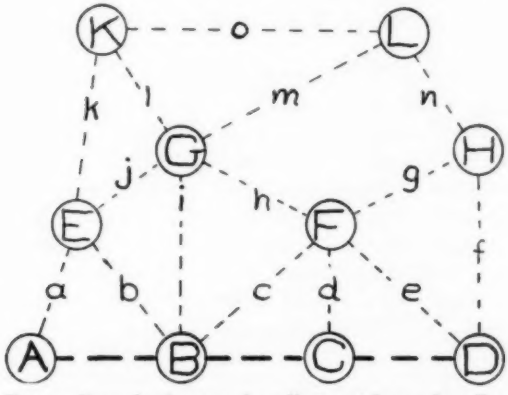


FIG. 1.—Example of progressive adjustment from a base line.

all directions. This method is relatively simple and rapid, but practically is not as simple or rapid as the uninitiated might expect and is not so rule-of-thumb as it might seem at first. The resulting picture of the gravity situation is warped irregularly; it reveals the major features fairly satisfactorily but may obscure or distort the minor features and the details of the major features, and may introduce anomalies which have no existence in nature.

The adjusted values obtained by all the preceding methods are only very crude approximations to the most probable values except for the case of a single closed traverse. The most probable value depends upon an adjustment which takes into consideration all the relations affecting the value of that particular station, which means that to obtain the most probable value for a single station all stations must be taken into consideration. The danger in the use of the preceding methods of adjustments—except in the case of a single closed traverse—lies in the fact that first only a small part of a survey is taken into account at one time; and second, the part of the survey already adjusted is regarded as being without error and any error of closure in a circuit under adjustment is regarded as lying wholly in that circuit. Simultaneously to take account of all stations in a survey in obtaining the most probable value for one or all of the stations, it is necessary to make use of the method of least squares.

ADJUSTMENT BY METHOD OF LEAST SQUARES

The method of adjustment by least squares may be illustrated by the adjustment of the survey of four stations of Figure 2 *C*. Let X_o be the value of gravity (or of magnetism) at station *O*, let *W*, *Y*, and *Z* be the most probable values for stations *W*, *Y*, and *Z* and let *a*, *b*, *c*, *d*, *e*, *f*, be the observed difference in intensity between the respective stations, and let E_1, E_2, et cetera, be small residual differences between observed and adjusted values. All the relations between X_o, *W*, *Y*, and *Z* should be written and are:

$$
\begin{aligned}
W - Y - a &= E_1 \text{ or squared } & W^2 + Y^2 + a^2 - 2WY - 2aW + 2aY &= E_1^2 \\
Y - Z - b &= E_2 & Y^2 + Z^2 + b^2 - 2YZ - 2bY + 2bZ &= E_2^2 \\
Z - W - c &= E_3 & Z^2 + W^2 + c^2 - 2ZW - 2cZ + 2cW &= E_3^2 \\
W - X_o - d &= E_4 & W^2 + X_o^2 + d^2 - 2WX_o - 2dW + 2dX_o &= E_4^2 \\
Y - X_o - e &= E_5 & Y^2 + X_o^2 + e^2 - 2YX_o - 2eY + 2eX_o &= E_5^2 \\
Z - X_o - f &= E_6 & Z^2 + X_o^2 + f^2 - 2ZX_o - 2fZ + 2fX_o &= E_6^2
\end{aligned}
$$

FIG. 2.—Simple types of system of closed traverses occurring in torsion-balance surveys.

Then

$$(E_1^2+E_2^2+E_3^2+E_4^2+E_5^2+E_6^2) = 3W^2+3Y^2+3Z^2+3X_o^2-2WY-2WZ-2WX_o-2YZ-2YX_o-2ZX_o-2(a-c+d)W+2(a-b-e)Y+2(b-c-f)z+2(d+e+f)X_o+a^2+b^2+c^2+d^2+e^2+f^2.$$

By the theory of least squares,[1] the values of W, Y, Z will be the most probable ones when the quantity $(E_1^2+E_2^2+E_3^2+E_4^2+E_5^2+E_6^2)$ is at a minimum.

By the theory of calculus, that quantity will be at a minimum when W, Y, and Z are such that the respective first derivatives of that quantity in respect to W, Y, and Z are equal to zero. By successive partial differentiation of B in respect to W, Y, and Z, the following so-called normal equations (4) are obtained:

$$\frac{\partial(E_1^2+E_2^2+E_3^2+E_4^2+E_5^2+E_6^2)}{\partial W} = 2X3W-2Y-2Z-2X_o-2(a-c-d)=0.$$

$$\frac{\partial(E_1^2+E_2^2+E_3^2+E_4^2+E_5^2+E_6^2)}{\partial Y} = -2W-2X3Y-2Z-2X_o+2(a-b-e)=0.$$

$$\frac{\partial(E_1^2+E_2^2+E_3^2+E_4^2+E_5^2+E_6^2)}{\partial Z} = -2W-2Y+2X3Z-2X_o-2(b-c-f)=0.$$

The values of W, Y, and Z can then be obtained by the solution of equations (4).

This simultaneous least-square adjustment of all stations increases rapidly in tediousness with increase in the number of stations. There

[1]The significance of the least square may be visualized most easily if it is analyzed in analytic geometry. If X, Y, and Z are the most probable values of three mutually dependent quantities and if X_1, Y_1, and Z_1 are observed values for X, Y, Z, then (X, Y, and Z) and (X_1, Y_1, and Z_1,) may be regarded as the coördinates of two points; and if E_1, E_2, and E_3 are the respective residual errors between the observed and the most probable values, then

$$X - X_1 = E_1,\ Y - Y_1 = E_2, \text{ and } Z - Z_1 = E_3$$

$$(X-X_1)^2+(Y-Y_1)^2+(Z-Z_1)^2 = (E_1^2 + E_2^2 + E_3^2)$$

The quantity $(E_1^2 + E_2^2 + E_3^2)$ is the algebraic expression for the diagonal distance between the two points. The two points will be the closest together when the diagonal distance is at a minimum; that is, the values of X_1, Y_1, Z_1, and X, Y, Z will be closest together when $\sqrt{(E_1^2 + E_2^2 + E_3^2)}$ is at a minimum. For four or more unknowns, the algebraic significance of the least square remains the same, although the geometric significance can not be visualized.

are as many unknowns as there are stations whose respective most probable values must be obtained. The solution of simultaneous first degree equations with many unknowns is extremely tedious and by the average calculator can be done successfully only if a suitable system of checks are used. For the solution of the normal equations a method was devised by Gauss which systematizes the work and provides a routine system of checks. But even with the use of the Gaussian method, the simultaneous adjustment of a survey of 200 stations will take the average calculator four to eight weeks of steady work. The degree of accuracy necessary in most practical work does not require a completely simultaneous adjustment of all stations, but can be obtained by a simultaneous adjustment of a net of primary stations and a secondary and in some cases tertiary adjustment of other stations.

LEAST-SQUARE ADJUSTMENT OF SIMPLE COMBINATIONS OF CLOSED TRAVERSES

The simplest case for adjustment is one in which all the stations can be regarded as lying in a net of traverses as, for example, those illustrated in Figure 2 or in yet more complicated nets of traverses.

Rule-of-thumb formulae can be constructed to express the results of the general algebraic solution of the adjustment for all such commonly occurring combinations of traverses, and the formulae can be cast in tabular forms for calculation which are very simple to use.

For Case *A*, Figure 2, $X_1 = X_o + \frac{a+b+c}{3}$ if the three traverses are all equally good, where X_o is the known or assumed value for station *O* and X_1 is the most probable value for station 1, and where a, b, c, are the respected observed differences of intensity along the traverses a, b, and c, and similarly for the other cases yet to be considered. But traverse "*b*," in general, will be shorter and will have less probability of error, than traverses "*a*," and "*c*," and of "*a*" and "*c*" one will have more probability of error than the other.

If the respective relative weights of dependence which can be placed on a, b, c are m, n, p, then $X_1 = X_o + \frac{ma+nb+pc}{m+n+p}$

For Case *B*, Figure 2, a general algebraic solution of the adjustment has been made and the formula expressing it has been cast in the tabular form of Figure 3. To get the most probable values for W, Y, and Z, the value for X_o and the respective values for a, b, c, d, e, f with proper algebraic sign are entered each in the proper space in column I, and each is multiplied successively by the coefficients of its row; the respective pro-

A I	II	III	IV
X_0	+1.00	+1.00	+1.00
a	+0.25	+0.42	+0.15
b	+0.25	+0.42	+0.15
c	+0.25	+0.08	−0.15
d	+0.25	+0.08	−0.15
e	+0.50	+0.17	+0.65
f	+0.50	−0.17	+0.35
	W = .	Y =	Z =
B			
X_0	+1.00	+1.00	+1.00
a	+0.16	+0.25	+0.10
b	+0.34	+0.55	+0.20
c	+0.34	+0.15	−0.20
d	+0.16	+0.05	−0.10
e	+0.50	+0.17	+0.65
f	+0.50	−0.17	+0.35
	W =	Y =	Z =

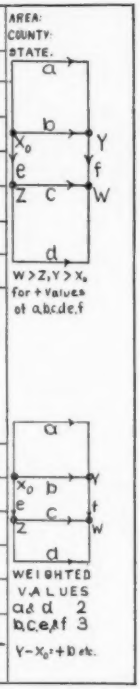


FIG. 3.—Calculation form for least-square adjustment of case *B*, Figure 2.

ducts are entered with proper algebraic sign in the proper space in the columns II, III, and IV. The algebraic sum of all the products in column II gives the most probable value for *W*, of column III for *Y*; and of column IV for *Z*. The coefficients in the tabular form of Figure 3*A* are based on the assumption that traverses *a*, *b*, *c*, and *d* are equally good. The coefficients in a tabular form of Figure 3*B* are based on the assumption that traverses *b* and *c* are worthy of slightly more weight than traverses *a* and *d*. In the calculations, a weight of 3 has been given to traverses *b* and *c*, and a weight of 2 to traverses *a* and *d*.

For Case *C*, the calculation form similar to that for Case *B* of Figure 2 is given in Figure 4. These coefficients were obtained by the solution of the normal equation (*4*). They are based on the assumption that all traverses have equal weight.

X_0	+1.00	+1.00	+1.00
a	+0.25	−0.25	0.00
b	0.00	+0.25	−0.25
c	−0.25	0.00	+0.25
d	+0.50	+0.25	+0.25
e	+0.25	+0.50	+0.25
f	+0.25	+0.25	+0.50
	Y =	Z =	W =

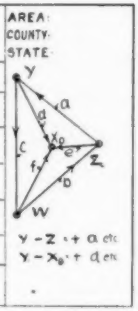


FIG. 4.—Calculation form for least-square adjustment of case *C*, Figure 2.

X_0	+1.00	+1.00	+1.00	+1.00
a	−0.27	+0.27	+0.07	−0.07
b	−0.07	−0.27	+0.27	+0.07
c	+0.07	−0.07	−0.27	+0.27
d	+0.27	+0.07	−0.07	−0.27
e	−0.47	−0.20	−0.13	−0.20
f	−0.20	−0.47	−0.20	−0.13
g	−0.13	−0.20	−0.47	−0.20
h	−0.20	−0.13	−0.20	−0.47
	X_1 =	X_2 =	X_3 =	X_4 =

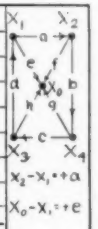


FIG. 5.—Calculation form for least-square adjustment of case *D*, Figure 2.

For Case *D*, the corresponding form is given in Figure 5. The coefficients are calculated on the assumption that all traverses have equal weight.

Similar forms can be made up without difficulty by a mathematician for all the more common combinations of traverses and kept on file ready for use. The actual use of any one of the forms requires only elementary mathematical skill and the calculations can be done by an ordinary calculator and require little time.

The preceding adjustment gives the most probable value for certain primary key stations chosen where traverses come together. The other stations on those traverses must be adjusted to those most probable values of the primary stations. The adjustment is made by taking the error between the adjusted and the observed value of the difference in gravity (or magnetism) for any given line and distributing it linearly back through the line, that is, if in Figure 6 X_m and X_n are any two

adjacent primary stations with most probable values of 100 and 200 respectively, if x_1, x_2, x_3 are secondary stations on a traverse, and if the observed difference in intensity X_m to x_1 is $+60$, x_1 to x_2 $+40$, x_2 to x_3 -20, and x_3 to X_n is $+40$:

The adjusted difference in intensity between stations X_n and X_m then is 100, and the observed difference is *120*.

An error of $+20$ must be distributed linearly through the line and is distributed respectively as follows:

$\frac{+60}{120} \times 20$ between X_m and x_1; $\frac{+40}{120} \times 20$ between x_1 and x_2; $\frac{-20}{120} \times 20$ between x_2 and x_3, and $\frac{+40}{120} \times 20$ between x_3 and X_n, and the adjusted differences between the stations will be:

$$+50,\ +33,\ -16,\ +33.$$

The adjusted, most probable, values of x_1, x_2, and x_3 then will be respectively *150*, *183*, and *167*.

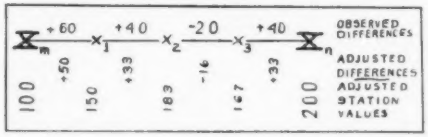


FIG. 6.—Linear adjustment of error between two adjacent key stations.

PRIMARY-NET METHOD OF LEAST-SQUARE ADJUSTMENT OF TORSION-BALANCE SURVEYS

The primary-net method of adjustment of Baron Eötvös may be used on a torsion-balance survey in which the stations are scattered rather uniformly throughout the area of the survey. A primary net of lines is chosen more or less arbitrarily and a primary adjustment is made by the method of least squares to obtain the most probable values for the key stations of the primary set.

The choice of the primary net and key stations may be explained by reference to Figure 7. Stations are assumed to be scattered at rather regular intervals throughout the survey. If the value of gravity is known for any station, that station would be chosen as the base station, but

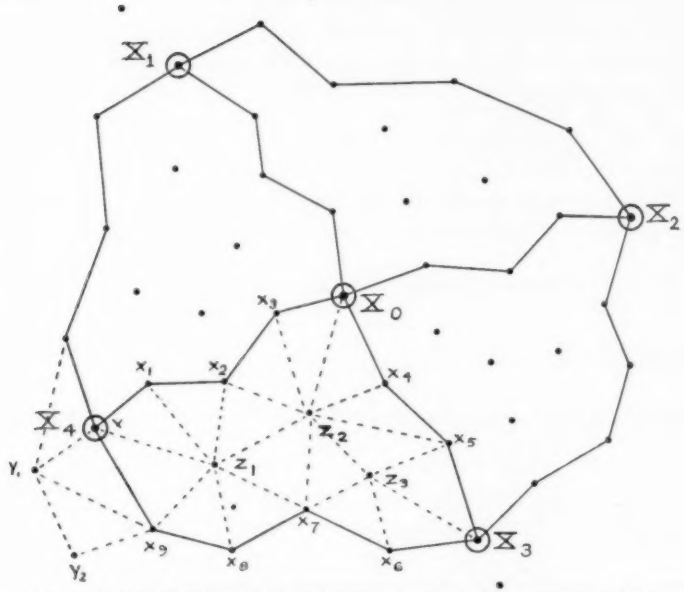


FIG. 7.—Sketch map illustrating primary-net method of least-square adjustment of a torsion-balance survey.

in the absence of such a station, station X_0 is chosen arbitrarily on the basis of its central position, and is assigned an arbitrarily chosen value for gravity.

Zigzag radial lines are run outward from station to station to the edge of the survey as in Figure 7, and the terminal stations are connected by a peripheral line. A few outlying stations in many surveys preferably may be left outside the peripheral primary line. If it is possible, the lines of the primary net should be run to avoid stations with eccentric values or areas where there is general discordance between adjacent stations. The primary adjustment for the most probable values of gravity for the key station X_1 to X_4, and the subsequent secondary linear adjustment for the most probable values of the secondary intermediate station, x_1 to x_9 on the lines of the primary net is the same as the adjustment in Case *D*, Figure 2.

The adjustment of the tertiary stations to the adjusted values of the primary and secondary stations is, and would most accurately be, made by the method of the least squares. The equations would be writ-

ten for each connection of the tertiary stations of each primary triangle, for example, z_1 and x_7, z_1 and x_8, z_1 and x_9, z_1 and X_4, z_1 and x_1, z_1 and x_2, z_1 and z_2, and similarly for z_2 and z_3. The so-called normal equations would then be written and solved. For the practical purposes of most commercial surveys, it is not necessary to go to the trouble of making the least-square adjustment; it is sufficient to use the mean values; that is, for station z_1, the values would be determined from x_7, x_8, x_9, X_4, x_1, x_2, and the mean of the values determined via z_2 from X_3, X_0, X_4, and x_5; and the mean of those seven values is used as the most probable value for z_1. Station z_2 is then adjusted with reference to the adjusted values of z_1, x_2, x_3, X_0, X_4, z_3 via x_5 and x_7, and from x_7, et cetera.

Any stations, such as y_1 and y_2, outside the peripheral line of the primary net, are adjusted in a similar manner to the nearest stations already adjusted.

The danger in the use of the primary-net method of adjustment lies in the fact that the primary adjustment depends wholly on the stations lying on the lines of the primary net, and the effect of the other stations is wholly neglected. The greater the percentage of the stations included in the lines of the primary net, the less is the deviation of the adjusted from the respective most probable values obtained by a completely simultaneous adjustment. If a calculator is available who understands the mathematics of a simple least-square adjustment, the survey should be cut up as the mutual arrangement of its stations demands, so that there are not more than 15, preferably not more than 10, key stations. The calculator can then make an original least-square adjustment of the primary net. If that is done, it takes only slightly longer first to make a general algebraic solution of the adjustment, and the coefficients obtained can then be filed for future use. If faint anomalies are to be studied, the primary-net method may not be sufficiently accurate and it may be necessary to make a completely simultaneous adjustment. The lines of the traverses of Figure 2 may be used as the primary nets for more extensive surveys.

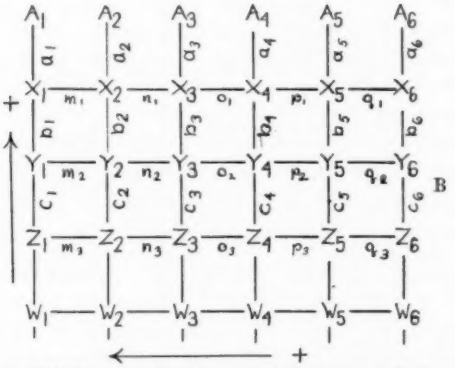
SCHEME OF LEAST-SQUARE ADJUSTMENT FOR SECTIONIZED COUNTRY

In sectionized country, rule-of-thumb forms of the type of Figure 8 *A* and *B* may be used for a semi-simultaneous adjustment of many torsion-balance surveys. The form in Figure 8*A* is constructed for use in a survey with stations at the corners of sections in a belt five sections wide and many sections long. The presence of additional stations on

CALCULATION FORM for
LEAST SQUARE ADJUSTMENT

A 6	+ 524	+ 219	+ 111	+ 065	+ 045	+ 036
A 5	+ 219	+ 416	+ 174	+ 090	+ 057	+ 044
A 4	+ 111	+ 174	+ 395	+ 165	+ 090	+ 065
A 3	+ 065	+ 090	+ 165	+ 395	+ 174	+ 111
A 2	+ 044	+ 057	+ 093	+ 174	+ 416	+ 219
A 1	+ 036	+ 045	+ 065	+ 111	+ 219	+ 524
a 1	- 524	- 219	- 111	- 065	- 045	- 036
a 2	- 219	- 416	- 174	- 090	- 057	- 044
a 3	- 111	- 173	- 395	- 165	- 090	- 065
a 4	- 065	- 090	- 165	- 395	- 174	- 111
a 5	- 044	- 057	- 090	- 174	- 416	- 219
a 6	- 036	- 045	- 065	- 111	- 219	- 524
q 1	- 265	+ 137	+ 063	+ 025	+ 012	+ 008
p 1	- 109	- 242	+ 221	+ 075	+ 032	+ 021
o 1	- 045	- 084	- 230	+ 230	+ 084	+ 045
n 1	- 021	- 032	- 075	- 221	+ 242	+ 109
m 1	- 008	- 012	- 025	- 063	- 137	+ 305
b 6	+ 111	- 023	- 047	- 041	- 032	- 026
b 5	- 023	+ 146	- 016	- 039	- 036	- 032
b 4	- 047	- 016	+ 154	- 011	- 039	- 040
b 3	- 040	- 039	- 011	- 154	- 016	- 047
b 2	- 032	- 036	- 039	- 016	+ 146	- 023
b 1	- 026	- 032	- 040	- 047	- 023	+ 111
q 2	- 111	- 026	+ 032	+ 023	+ 016	+ 013
p 2	- 084	- 060	+ 051	+ 048	+ 035	+ 023
o 2	- 052	- 062	- 064	+ 064	+ 062	+ 052
n 2	- 023	- 035	- 048	- 051	+ 080	+ 084
m 2	- 013	- 016	- 023	- 032	- 028	+ 111
c 6	+ 059	+ 005	- 015	- 018	- 016	+ 015
c 5	+ 305	+ 388	+ 032	- 013	- 016	+ 018
c 4	- 015	+ 002	+ 040	+ 003	- 014	+ 018
c 3	- 018	- 014	+ 003	+ 040	- 002	+ 015
c 2	- 016	- 018	- 013	+ 002	+ 038	+ 005
c 1	- 015	- 016	- 018	- 015	+ 005	+ 059
q 3	- 058	- 005	+ 015	+ 018	+ 016	+ 015
p 3	- 064	- 044	+ 013	+ 031	+ 033	+ 031
o 3	- 049	- 046	- 027	+ 027	- 046	+ 049
n 3	- 031	- 033	- 031	- 013	+ 044	+ 064
m 3	- 015	- 016	- 015	- 015	+ 005	+ 356
	$\times_6 =$	$\times_5 =$	$\times_4 =$	$\times_3 =$	$\times_2 =$	$\times_1 =$

A



B

FIG. 8.—*A*. Calculation form for scheme of least-square adjustment in sectionized country. *B*. Plan of arrangement of stations for the scheme of least-square adjustment in sectionized country.

the section lines is immaterial. The assumption is made that intensity of gravity at each station of the first row (stations $A_1, A_2, A_3, A_4, A_5, A_6$, of Figure 8*B*) is known and in general it will be necessary to make the line A_1 to A_6 a base line by taking a sufficient number of intervening stations with the torsion balance. The most probable values for the second row of stations, X_1, X_2, X_3, X_4, X_5, and X_6, are adjusted on the basis of the known values for stations A_1, A_2, A_3, A_4, A_5, and A_6 and on the basis of the observed differences along section lines calculated by the use of the gradients at stations A_1 to A_6, X_1 to X_6, Y_1 to Y_6, and Z_1 to Z_6. The values for those observed differences between stations, that is, a_1, a_2, et cetera, are entered in the proper places in the form of Figure 8*A*, and then are multiplied by the proper coefficients, in a manner corresponding with that in the use of the forms of Figure 3.

The adjusted values for the next row of stations, Y_1 to Y_6, are obtained in the same manner, when the adjusted values have been obtained for stations X_1 to X_6. For this calculation, the adjusted values of the old X stations become the new A's, the old Y's become the new X's, the old Z's become the new Y's, the old W's become the new Z's, the old b's become the new a's, the old m_2 becomes the new m_1, et cetera; all the values are entered in their proper new places on a blank of the form of Figure 3, and the calculation is gone through again in the same way as before. The adjusted values for the succeeding rows of stations are made by similar successive shifts of the position of the calculation form. For the adjustment of the last two rows, the form of Figure 8*A* is not applicable.

ADJUSTMENT OF THE GRADIENT

The gradient as well as relative gravity may be adjusted in torsion-balance surveys, but the adjustment of the former is much more tedious and the adjusted gradients have certain disadvantages in interpretation. The methods of adjustments just discussed are for the adjustment of the relative value of the intensity of gravity for the several stations of the survey. The respective azimuths and magnitudes of the gradient at the several stations of the survey can be adjusted in an entirely similar manner. The necessity of adjusting both the magnitude and the azimuth of the gradient make the computations much more tedious than the computations in the adjustment of relative gravity.

ADJUSTMENT OF MAGNETOMETER SURVEYS BY FORMULAE OF FIGURE 8

The adjustment of magnetometer surveys may be made by the methods just described for the adjustment of torsion-balance surveys

where the stations are scattered rather uniformly throughout the area of the survey, but the magnetometer surveys must have been run with that type of adjustment in view.

If two profiles are run with torsion balance and with magnetometer stations at all section corners on adjacent east-west section lines, the probable accuracy of the calculated difference in gravity between adjacent stations is the same in the north and south and the east and west directions. No value can be obtained for the difference of the intensity of magnetism between adjacent stations in north and south directions if the two profiles are not tied together. And even if the two profiles are tied together at both ends and adjusted as a closed circuit, the difference of intensity between adjacent stations in north and south directions does not have nearly as high a probability of accuracy as in the east and west directions, except where the adjacent stations in north and south directions were tied together by a north-south traverse. For the purposes of adjustment in magnetometric surveys, no value for the difference in the intensity of magnetism between stations may be used except where a tie line has actually been run between the stations. A magnetometer survey should be planned in advance in accordance with the type and plan of adjustment which is to be used.

For magnetometer surveys in sectionized country, the scheme of adjustment underlying the form of Figure 8 may be used in several ways.

A. The width of the unit rectangles such as A_1-A_2-X_2-X_1 may be extended to 2, 3, 4, 5, 6, or more miles; closed traverses may be run for the unit rectangles in the manner indicated by Figure 9 and the error of closure of each adjusted linearly back through its line. The ties X_1-Y_1, et cetera, would be run as $X_1 - Y_1 - X_1$. The adjustment for the key stations $X_1, X_2 \ldots . Y_1, Y_2, \ldots .$ et cetera, would be made by the use of the form of Figure 8*A*. If the unit closed traverses are planned so that each makes a forenoon or afternoon's run, the scheme of Figure 9 has the advantage that the diurnal effect is largely eliminated, the effect of many magnetic storms is eliminated, minor errors are partly adjusted, and the presence of large errors is speedily detected and localized within a short traverse which can be immediately re-run, and that results are then in such a form that the whole survey may be readily adjusted.

B. For work requiring slightly less accuracy, north-south and east-west traverses may be run back and forth completely across the area of the survey without checking back to form closed traverses. The observer, however, should immediately re-check any tie between stations where there is a large, abrupt, suspicious jump or drop in the relative

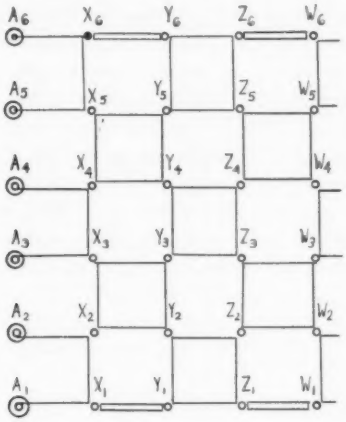


FIG. 9.—Plan of traverses in a magnetometric survey to be adjusted by the calculation form of Figure 8 *A*.

intensity measured. If the effects due to the lesser magnetic storms and to the diurnal fluctuations are not corrected by comparison of the observations with a recording instrument, the observer should take care to stagger the noon, the morning, and the night positions of the various traverses irregularly over the survey before the adjustment is made; the days of serious magnetic storms during the period of the survey should be ascertained from the Tucson magnetic observatory or other magnetic observatories, and the traverses made on those days should be re-run or neglected. For either *A* or *B*, the line $A_1 \ldots\ldots A_6$ must be run out as a base line. The adjustment is made for either *A* or *B* by taking the differences between the adjacent *A*, *X*, *V*, *Z*, *W*, et cetera, stations by entering them on their proper places in the form of Figure 8*A*, and proceeding in the same way as in the adjustment of a torsion-balance survey.

IMPORTANCE OF ADJUSTMENT OF SURVEYS

The importance of the adjustment of magnetometer and torsion-balance surveys is not recognized by many geologists, and the geophysicist may have difficulty in getting a chance to get the stations or tie lines technically necessary for a proper adjustment. Most experienced geologists realized the necessity for closing plane-table, alidade traverses in mapping key beds, and have a keen realization of the irregularities of structure which show up in structure contours based on "wild" tra-

verses, which were never tied together or completely tied to known bench marks. A series of "wild" plane-table traverses not tied together or to known bench marks, give very considerable information about the structure immediately along each traverse, but give only a very hazy picture of the structure of the area as a whole. Very much more information immediately becomes available when the various "wild" traverses have been tied together. The situation is entirely similar with torsion-balance and magnetometer surveys. Profiles not tied together give much information about the situation along the particular line of traverse, but the areal situation becomes clear only when the lines have been tied together and the survey adjusted.

The danger in the attempt to picture the areal situation from lines not tied together, closed, and adjusted can be visualized by reference to Figure 10.

The block diagram of Figure 10, *A* is the geometrical representation of a sloping plane surface of gravity or magnetism, in which the vertical ordinates represent the intensity of gravity or magnetism. In Figure 10, *B*, three wild profiles, *ABC*, *AD*, and *AFE* are represented. A negative error is assumed at point "*a*" in profile *ABC*, a positive error is assumed at point "*b*" in profile *AD*, and two negative errors respectively at "*c*" and "*d*" in profile *AFE*. The other parts of the two traverses are assumed to be without error. The isogams drawn through the three profiles picture a nose which has no existence in nature. In Figure 10, *C* the three traverses are represented as having been tied together and then adjusted. Figure 10 illustrates also the fact that the isogams based on the adjusted values of the traverse deviates slightly from the true isogams. They give only the most probable values in the light of all the observed values in the system. No method of adjustment will eliminate errors in the observations and give true values. The adjustment merely gives a value that is a compromise between the conflicting observations of the relations which must be used to obtain the value for the particular quantity. Adjustment gives no assurance of obtaining true values from poor observations.

The failure properly to adjust surveys in general will produce false anomalies where no anomalies are present, and will distort and obscure anomalies which actually exist. These false anomalies may be, but are not necessarily, recognizable as such. On account of the assistance given by the gradient and differential curvature such false anomalies are more easily detectable in torsion-balance than in magnetometer surveys.

FIG. 10.—Block diagrams illustrating danger in failing to close and adjust traverses. *A*. Plane sloping surfacing, with evenly spaced, parallel contours. *B*. Form of the surface and the contours as inferred from the unclosed and unadjusted traverses *AC*, *AD*, and *AE*. C. Form of the surface and the contours as inferred from the closed and adjusted traverses *AFED*, *AD*, and *ABC*.

REFERENCES

ERRORS IN THE USE OF MAGNETOMETERS

C. A. Heiland, "Theory of Adolf Schmidt's Horizontal Field Balance," *Amer. Inst. Min. Met. Eng.*, Volume on *Geophysical Prospecting* (1929), pp. 261-314.

C. A. Heiland, "Construction, Theory, and Application of Magnetic Field Balances," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 1189-1200.

H. Haalck, *Die magnetischen Verfahren der angewandten Geophysik* (Berlin, 1927).

C. A. Heiland and P. Duckert, "Beschreibung, Theorie und Anwendung einer Neukonstruktion von Ad. Schmidts Feldwage, *Zeit. für angewandte Geophysik*, Bd. 1, Heft 10 and 11 (1924).

METHOD OF LEAST-SQUARE ADJUSTMENT

F. R. Helmert, *Die Ausgleichungsrechnung nach der Methode der kleinsten Quadrate*, 3rd edition. B. G. Teubner (Leipzig and Berlin, 1924).

T. W. Wright and J. F. Hayford, *The Adjustment of Observations by the Method of Least Squares with Application to Geodetic Work*, Van Nostrand Company, New York.

C. L. Crandall, *Textbook on Geodesy and Least Squares*, John Wiley & Sons, 1st edition (1907), Part II, pp. 205-95.

C. H. Birdseye, "Topographic Instructions of the U. S. Geological Survey," *U. S. Geol. Survey Bull. 788* (1928), pp. 71-82.

GEOLOGIC AND ECONOMIC NOTES ON VENEZUELAN OIL DEVELOPMENTS[1]

EDWIN B. HOPKINS and H. J. WASSON[2]
New York, N. Y.

ABSTRACT

Venezuelan oil importance rests on three factors: (1) large reserves, (2) favorable legal and political situation, and (3) economic advantages over many other sources of oil.

The first two points are touched on briefly, and the third is more fully developed to include certain conclusions with respect to market zones in general and the influence of Venezuelan oil in particular on sources of production in the United States.

The conclusion is that Venezuela and other sources of low-cost oil, such as the West Texas, California, and the Gulf Coast, will displace increasing amounts of Mid-Continent oil in the Atlantic Seaboard market, and that Mid-Continent oil, if so confined to its normal economic market, may yield to its owners a greater ultimate profit.

INTRODUCTION

Venezuela is at the present time firmly entrenched in the position of second oil-producing country of the world; and there is every reason to believe that it will maintain this status for an indefinite period.

Three important factors contribute to support this prediction: (1) plentiful reserves of oil in sight, and in fairly certain prospect; (2) equitable laws for the control of its oil business; and (3) especially favorable geographic position and low production costs, placing the country in very advantageous position for participation in markets of the Atlantic states.

The enormous oil potentialities of the country, and its strategic position with respect to the United States, are indisputable facts, leaving the continuance of the present favorable political situation as the only variable in the general situation.

From a purely geological standpoint, the various aspects of these oil occurrences would alone be appropriate subjects for discussion. However, at this particular time an increasing proportion of geologic thought is devoted to the economic phases surrounding the industry,

[1]Read before the Association at the Fort Worth meeting, March 21, 1929. Manuscript received by the editor, March 11, 1929.

[2]Consulting geologists, 25 Broadway.

and it is thus felt that a broader consideration of the Venezuelan oil situation is of more general interest. Accordingly, in this paper an attempt is made to point out briefly some of the important points of the general subject, following the order in which the three main controlling factors, geologic, political, and economic, are stated.

OIL OCCURRENCES AND EXPLORATION

From a geologic standpoint, the Venezuelan fields are of two easily recognizable types. Of first importance, at least up to the present, are the accumulations on monoclines; and in a rather subordinate position are the fields related to the classic anticlinal or domal structure.

The prolific lake-shore fields on the east side of Lake Maracaibo, which include the Ambrosio, La Rosa, Punta Benitez, Tia Juana, and Lagunillas areas (mentioned in order from north to south, not in order of importance) are disposed along a 30-mile stretch of territory that structurally is a normal part of a broad west-dipping monocline. This flank, its east-dipping counterpart on the west side of the lake, and the north-dipping components at the south end of the region,—all combine to form the geosynclinal area known as the Maracaibo Basin.

Development along this monocline shows no pronounced evidence of either strike or transverse folding, and only minor faulting, seemingly without important effect on the distribution of the oil. The only well established irregularities in the beds seem to be a series of transverse (approximately northeast-southwest) corrugations which are thought to be of erosional origin. The configuration of the top of the formations unconformably underlying the oil measures has probably been a controlling influence effecting these irregularities; and it is a curious fact that much of the best production is from the depressions between the crests. In a few places the oil zone is thin or absent over the high parts of the corrugation, and the unconformable relationship between the oil sands and the underlying formations seems to be thoroughly established.

The Mene Grande field, also on the east side of the lake, but south of the lake-shore producing area, is inland about 10 miles, and on the edge of a foothill belt in which folding parallel with the general monoclinal strike is probably related to the oil accumulation. The evidence of present development indicates the existence at Mene Grande of an asymmetric anticline plunging sharply toward the south, with its west or lakeward limb dipping very steeply, and the east side, not so well defined, dipping comparatively gently into a minor syncline, which separates it from the mountain uplift farther east. Exactly how much the

structural conditions at Mene Grande contributed to the oil accumulation, or whether the association of the two is possibly only the result of coincidence, is not entirely clear. Inasmuch as the La Rosa-Lagunillas monoclinal oil occurrences in formations of similar age are only a few miles away, and inasmuch as the Mene Grande, though the oldest field in Venezuela, is still only partly defined, it is difficult to classify it with certainty as a true anticlinal accumulation.

La Concepcion and La Paz, on the west side of the lake, in the district of Maracaibo, are typical anticlinal accumulations. The same is true of the Rio de Oro and the Tarra fields in the southwest part of the basin, and possibly the El Mene field northeast of La Rosa, and out of the basin proper, though here accumulation against a fault plane may be the important factor. The new field, near Urumaco, state of Falcon, recently opened by the Standard Oil of California-Sun Company interests still farther east of El Mene, is located on a clearly defined domal structure; and the field of the North Venezuelan Petroleum Company in the eastern extremity of Falcon is closely related to typical anticlinal folding.

The monoclinal area on the lake shore has so far proved to be of the greatest economic importance, and in this belt, still far from being delimited, there are proved reserves in sight which must be measured in the hundreds of millions of barrels.

The occurrence of the oil in the lake field—and it is fairly safe to call the entire area one field, even though there are still some unproved gaps—is similar to the occurrences on the west side of the Coalinga Valley, California. The age of the oil formations known as the La Rosa series, is lower Miocene, or Oligocene. The oil-bearing formation is, as in California, properly described as a zone in which oil-saturated sands alternate with shales throughout varying intervals, in some places thick, in others thin or entirely missing. The thickness of the pay part of the oil zone is so variable that it is difficult to give an average figure. So far nothing approaching the great thickness of the Ventura, Signal Hill, and other Los Angeles Basin oil zones, has been developed. Perhaps a figure of 300 feet for the oil zone would give a reasonable basis for comparison with California.

The total oil zone is, at least in La Rosa, split into two separate levels (or three if the "tar sand" is included), but the interval between them is not great, and as there is no intervening water, the two horizons, for practical purposes, constitute a single zone, and ordinarily are so regarded from a production standpoint.

The wells in the lake fields, as well as in Mene Grande, are characterized by high gas pressure, and the average flowing life in these fields is rather extraordinary. Examples of wells having flowed for several years are common; and the percentage of large individual well records is also noteworthy. In the Mene Grande field approximately 10 per cent of the 155 wells so far drilled will show individually more than 1,000,000 barrels ultimate extraction; and in Lagunillas a similar result seems probable.

Well spacing undoubtedly is an important factor in individual well accomplishment; thus, the record at Mene Grande, where the earlier wells were widely spaced, is hardly comparable with the record at Lagunillas, where a uniform spacing of one well for 8 to 10 acres has been followed, though obviously in both records very prolific producing territory is indicated.

As would be expected with wells of this character, the yield per acre will be very satisfactory. In the monoclinal fields and Mene Grande the recovery will exceed 50,000 barrels an acre, throughout very substantial areas. It is, of course, impossible at this time to approximate an average figure, as this will depend on the area of the lean territory that can be economically exploited.

The specific gravity of the oil in both the lake fields and Mene Grande ranges from 17° to 25° Bé. Curiously enough, though no structural significance may be indicated, the oil in the anticlinal fields is uniformly lighter, ranging from 25° in La Paz to 35°-40° in El Mene.

Aside from the fundamental structural difference, and the difference in gravity, the other distinguishing criteria of the anticlinal fields (unless Mene Grande is included) are thinner sand bodies, less gas pressure, lower initial production, and lower yield per acre. Indeed, the time-honored and classic conceptions of oil geology seem here to be reversed. This anomaly may be more seeming than real, however, as further development may conceivably find the combination of a Lagunillas type oil zone associated with a well defined anticline, and a resulting field surpassing anything so far encountered.

The search for this ideal field, as well as such average fields as may be discovered in passing, is now actively going on, and this entire exploration activity involves many angles, some of them quite new, which are of particular interest to the geologist.

Practically all of the exploration work, as well as the producing fields, are located in northwestern Venezuela (Fig. 1). Eastern Venezuela is also being systematically prospected both by drilling and geophysical surveys, though results to date are in no way comparable with those obtained in the Maracaibo Basin and the adjoining state of Falcon.

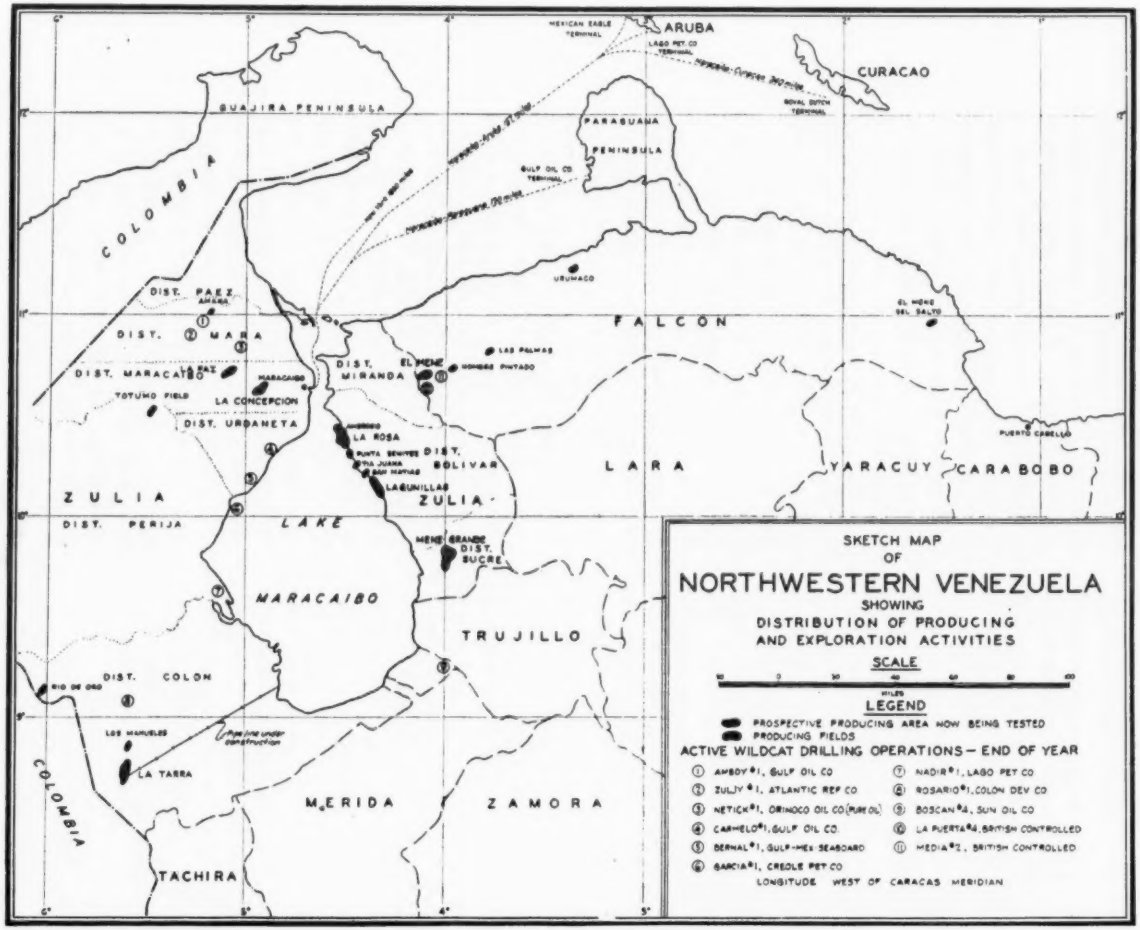

ARUBA
CURACAO
GUAJIRA PENINSULA
PARAGUANA PENINSULA
COLOMBIA
FALCON
DIST. PAEZ
DIST. MARA
DIST. MARACAIBO
DIST. MIRANDA
EL MENE
LAS PALMAS
HOMBRE PINTADO
MARACAIBO
LA CONCEPCION
TOTUMO FIELD
DIST. URDANETA
LA ROSA
PUNTA BENITEZ
PTA. JUANA
BAJO HONDO
LAGUNILLAS
DIST. BOLIVAR
ZULIA
LARA
YARACUY
CARABOBO
PUERTO CABELLO
DIST. PERIJA
LAKE MARACAIBO
MENE GRANDE
DIST. SUCRE
TRUJILLO
DIST. COLON
RIO DE ORO
LOS MANUELES
LA TARRA
COLOMBIA
M. ERIDA
ZAMORA
TACHIRA
SKETCH MAP
OF
NORTHWESTERN VENEZUELA
SHOWING
DISTRIBUTION OF PRODUCING
AND EXPLORATION ACTIVITIES
SCALE
MILES
LEGEND
PROSPECTIVE PRODUCING AREA NOW BEING TESTED
PRODUCING FIELDS
ACTIVE WILDCAT DRILLING OPERATIONS – END OF YEAR
① AMBOY #1, GULF OIL CO
② ZULJY #1, ATLANTIC REF CO
③ NETICK #1, ORINOCO OIL CO (RUN OIL)
④ CARMELO #1, GULF OIL CO.
⑤ BERNAL #1, GULF-MEX SEABOARD
⑥ GARCIA #1, CREOLE PET CO
⑦ NADIR #1, LAGO PET CO
⑧ ROSARIO #1, COLON DEV CO
⑨ BOSCAN #4, SUN OIL CO
⑩ LA PUERTA #4, BRITISH CONTROLLED
⑪ MEDIA #2, BRITISH CONTROLLED
LONGITUDE WEST OF CARACAS MERIDIAN

FIG. 1

As is generally known, Lake Maracaibo is surrounded by a belt of nearly flat lowland, bounded at distances ranging from 20 to 100 miles inland by a horseshoe-shaped belt of foothills and mountains, which enclose the entire lake basin except on the north. Most of the flat lowlands are covered with recent alluvium, many of them swampy, and devoid of workable outcrops. As the foothills are approached, the terrane exhibits more and more topographic relief, and exposures become more numerous. Rock exposures, however, and their structural interpretation, have so far contributed little to Venezuela's oil resources, even in the foothills where the geologic story is well revealed.

By far the most important factor in the explorations, up to very recent time, has been the presence of oil seepages, for which the basin is famous. Throughout the entire circle of the foothill belt, the exposed outcrops of the various oil horizons are marked by seepages, not continuous, of course, but of common occurrence. Taken together the seepages furnish one of the most suggestive indications of the great oil possibilities of the region.

The Mene Grande field was an obviously good prospect on the strength of the large seepages in the vicinity. The combination of these and favorable structure made this a logical starting point for exploration, but the seepages alone would have been ample.

Even out in the lowlands, far from the foothills, there are a few places where oil has seeped up to the surface, and these, naturally, received early investigation. Attention was first attracted to La Rosa by a small oil seepage near the lake shore, and the first well drilled was a small producer which led several years later to the actual discovery of the field. At La Paz the discovery well was located close to a large seepage; at Concepcion the presence of oil and tar encountered in test pits (though there were no seepages at the surface) largely led to the location of the discovery well; in like manner the discovery of El Mene and Totumo was solely the result of seepage indications; and Tarra and Rio de Oro, at least in part, were prospected for a similar reason. To date there is not a shipping field in the Maracaibo Basin the discovery of which can not be traced in part, at least, to the presence of near-by oil seepages, or, as with Lagunillas, to mere trend wildcatting ahead of a field so discovered.

The beginning of a new order of things is, however, making its appearance, and several recent discoveries have been the result of straight surface structure work, aided in part by geophysical methods. The Amana well of the Gulf Company, and the Netick well of The Pure Oil

Company, both in the district of Mara, though neither is as yet definitely established as of commercial importance, were located on a combination of surface and geophysical data.

The recent completion by the Standard of California-Beacon-Sun Company of a well rated at 1,200 barrels of initial production near Urumaco, in the state of Falcon, is thus far the outstanding accomplishment of exploration based solely on surface structure, and the only one considered positively to be of commercial importance.

In general, therefore, it may be said that the presence of seepages, carrying with them the quite obvious suggestion of near-by oil, has been overwhelmingly the most important factor in the development to date. In other words, the pioneer history of most oil countries has here repeated itself.

Looking into the future, however, it is evident that the next phase of the country's development will call forth, for the maintenance of reserves, the application of an exploration technique much more advanced than the satisfactory but haphazard methods heretofore employed.

At present there are many millions of dollars tied up in concessions which in a broad sense can be considered as "possible oil land," but which do not lend themselves to satisfactory classification by any of the former geological methods. Thus, one observes, in Venezuela, a rapid development in the use of geophysical methods, as well as a very keen interest in such subjects as micro-paleontology, heavy-mineral analysis, and all other modern helps available for use in connection with the difficult correlation problems inherent in the situation.

Sufficient time has not elapsed to measure the full value of the scientific methods brought to bear on the general exploration problem; and so much of this information is confidential that perhaps nothing of specific interest will ever get much publicity. However, as more and more wells are located in the flat country, far from seepages and evidence of surface structure, the results obtained will soon lead at least to some very interesting inferences with respect to the prospects for new oil fields in the Maracaibo Basin.

Aside from a widespread use of the seismograph, torsion balance, and magnetometer, several operators have made extensive use of the light core-drilling rig similar to those used for structure drilling in Kansas and Oklahoma, and previously test pits were dug on a fairly large scale.

Unlike the situation in Kansas and Ok'ahoma, the Miocene and later formations overlying the Venezuelan oil sands do not contain any of the regular limestone beds that provide such splendid markers in the

Mid-Continent. Recourse is had to very detailed study of the *Foraminifera*, together with determinations of the heavy minerals and the correlation of such few persistent horizons as may be recognized.

The geological test holes, as they are called, are put down either with a diamond drilling rig, or a light rotary outfit. Most of the formations being soft, diamonds are not used. Some of these holes are cored nearly throughout their full depth; others are drilled in part with fishtail bits. Depths of 2,000 feet have commonly been attained, but the average for holes of this type is approximately 1,500 feet. Some idea of the technical advance through which the industry is progressing is given by this activity, wherein one observes the seemingly casual drilling of 10 or 20 1,500-foot holes as a preliminary to any thought concerning the location of a regular oil-well test.

The present tendency, however, seems to be away from the geological test-hole work, and toward seismographic surveys. Where the two have been used in the same area, a favorable agreement in results is said to be indicated. Time, and a more extensive record of cost data, will determine whether the geologic test hole will continue to have a place in the exploration program, or whether, as seems probable, it will yield the field entirely to geophysical methods.

PETROLEUM LAWS AND GOVERNMENTAL BACKGROUND

Our own domestic oil activities, and those conducted throughout the British Empire, enjoy the maximum degree of security and freedom from governmental interference. In other parts of the world, there are only a few lands important in an oil sense which provide the oil operator with the legal and governmental protection conducive to the successful conduct of modern large-scale enterprises.

Foreign oil operations for the most part involve a constant clash between our views of legal equity and the much older and more widespread governmental philosophy which at heart has never departed far from the idea that the government of the state, and not the state itself, is the true political objective. There are a few exceptions, however, among which Venezuela, in recent years, has stood out prominently as a notable example of fair dealing between government and industry; and the material progress of the country, measured from all angles, bears eloquent evidence of the fundamental soundness of such a policy. There has been nothing weak or altruistic about Venezuela's intercourse with foreign industrialists. Substantial royalties, and taxation clauses have been written into the contracts covering the oil concessions, but—and

this is the important point—all of the obligations imposed on the exploitation of its resources were conceived on sound business principles. The executive skill of General Juan Vicente Gomez, the country's president, was brilliantly revealed in the preparation of the underlying petroleum laws, which preceded and paved the way for the present major activities. No wild experiments with half-baked economic theories were attempted, though at the time the world in many quarters was rumbling with the confused doctrines that have now come to be known as the nationalization movement. The petroleum law was the work of several of the best legal minds of the Republic, jointly with a committee of American advisers. Taking many good points from American practice, and adding special provisions adapted to Venezuelan conditions, the petroleum law as finally enacted afforded a simple, workable basis whereby the oil wealth of the nation could be exploited in such a manner as to yield a fair return to both the operator and the country. Thus the stage was set for the conduct of a great oil industry, enjoying the protection of a stable government, and in harmony with it.

In the opinion of most qualified observers, the present satisfactory condition is thought to rest on a safe foundation, notwithstanding certain recent and contemporary history in other parts of Latin America that might suggest skepticism. Many of us, and perhaps Americans in general, are inclined to be too intently wrapped up in our own progress to perceive the trend toward political enlightenment moving forward in many other parts of the world. In Venezuela this advance has been relatively great, and under the capable leadership of President Gomez, the country has enjoyed nearly twenty years of peace and progress. During this time, and especially during the latter years, since the stimulus of the oil activity has begun to make itself felt on the national treasury, a system of public schools has spread over the land; a network of good highways, involving the greatest road expenditure per capita in South America, has unified the republic and greatly strengthened its political coherence; the national debt has been reduced to insignificant proportions; the Venezuelan currency held at a stabilized exchange ratio with the American dollar for years; and lastly, the decade of intimate contact with major business operations, as exemplified by its oil industry, has provided a practical lesson in economics that has touched and benefitted a large percentage of the population.

Disturbing factions exist in all countries, and Venezuela is no exception. It is, however, extremely doubtful if the enlightened, responsible elements in this republic will be for long deluded by the demagogic

arguments of those political agitators who, screening their own subversive motives behind a false cry of patriotism confused with a barrage of ignorant and distorted economic fallacies, maintain the continual harassment of industrial enterprise which we notice on so many sides. Nor does it seem likely that the traditional friendship that has existed between the United States and Venezuela since the days of Simon Bolivar will be lightly disregarded.

We are considering here a national character temperamentally impulsive, but at the same time having a dependable capacity for friendship. So long as the policies and the attitude of our nationals in Venezuela are worthy of the hospitality they now enjoy, there are ample grounds for optimism concerning the future industrial relations.

ECONOMIC CONSIDERATIONS

The necessity of considering Venezuela as a definite major influence intimately related to the oil industry in the United States is now universally recognized. This South American country is by far the largest foreign competitor in our markets and, as shown in Table 1*A*, it is displacing substantial percentages of the domestic fuel and gas oil output, and a small but growing percentage of our gasoline supply.

The relative magnitude of this new factor in the situation is shown in another way, by the following comparison of the 1928 production for Venezuela and our five foremost oil states:

State	*Barrels*
Texas	255,354,357
Oklahoma	247,500,854
California	231,982,597
Venezuela	106,500,000
Kansas	38,150,878
Arkansas	32,137,934

It is quite unlikely that Venezuela will pass any of the three leading states for several years. Nevertheless it may be counted on to hold its own with the leaders, and for another year or so will probably show a relatively more rapid rate of increase.

All of these developments, so fraught with significance for American oil interests, seem logical, and, as we will attempt to show hereafter, more or less inevitable. How rapid will be the sweep of Venezuelan oil into our markets; who will suffer most; what can be done to prevent it, if anything; and just how serious is the menace after all, are live questions which are now receiving a great deal of attention. The writers, having observed closely through a period of years the phenom-

TABLE I-A

YEAR	TOTAL U. S. SUPPLY BARRELS		GASOLINE FUEL OIL AND GAS OIL IMPORTED DIRECTLY INTO U. S. FROM VENEZUELA. (A)			
	GASOLINE	GAS OIL AND FUEL OIL	GASOLINE	GAS OIL AND FUEL OIL	PERCENT OF U. S. SUPPLY	
					GASOLINE	GAS OIL FUEL OIL
1920						
1921	122,704,000	230,091,000				
1922	147,672,000	254,910,000	24,748	4,392	0.02	0.002
1923	179,903,000	287,480,000	46,271	87	0.03	0.000
1924	213,325,000	320,476,000	54,946	105,708	0.03	0.03
1925	259,601,000	364,991,000	435,993	478,708	0.2	0.1
1926	299,734,000	365,195,000	2,387,628	1,246,745	0.8	0.4
1927	335,047,000	401,190,000	2,501,846	1,553,520	0.7	0.4
1928	381,479,000	433,023,000	2,565,064	2,939,117	0.7	0.7

(A) INCLUDES REFINED PRODUCTS FROM REFINERIES LOCATED IN THE DUTCH WEST INDIES OPERATING ON VENEZUELAN CRUDE.

TABLE I-B

YEAR	IMPORTS OF VENEZUELAN CRUDE INTO U.S.	ADDITIONS TO U. S. SUPPLY OF REFINED PRODUCTS POSSIBLE FROM DIFFERENT METHODS OF REFINING VENEZUELAN CRUDE							
		QUANTITY BARRELS				PERCENTAGE OF TOTAL U S SUPPLY			
		STRAIGHT RUN		CRACKING		STRAIGHT RUN		CRACKING	
		12.5% GASOLINE	80% GAS OIL FUEL OIL	30% GASOLINE	60% GAS OIL FUEL OIL	GASOLINE	GAS OIL FUEL OIL	GASOLINE	GAS OIL FUEL OIL
1920	191	24	153	57	115				
1921	23,862	2,981	19,100	7,158	14,300				
1922	747,820	93,500	598,000	224,346	448,700	0.06	0.2	0.15	0.2
1923	809,883	101,235	647,000	242,964	485,000	0.05	0.2	0.13	0.2
1924	1,185,823	148,228	944,888	355,746	711,500	0.1	0.3	0.17	0.2
1925	4,692,349	586,569	3,750,000	1,407,705	2,805,000	0.2	1.0	0.5	0.8
1926	12,285,045	1,535,631	9,828,000	3,685,515	7,371,000	0.5	2.7	1.2	2.0
1927	21,560,000	2,695,000	17,248,000	6,468,000	12,900,000	0.8	4.3	1.9	3.2
1928	46,976,000	5,872,000	37,580,000	14,092,800	28,185,000	1.5	8.7	3.7	6.5

SUMMARY OF TABLES I-A AND I-B

YEAR	PERCENT OF U. S. TOTAL SUPPLY OF REFINED PRODUCTS FROM VENEZUELAN CRUDE REFINED IN U. S. PLUS IMPORTS OF REFINED PRODUCTS DIRECT. (A)	
	GASOLINE %	GAS OIL AND FUEL OIL %
1921		
1922	0.08 – 0.17 % OF TOTAL	0.202 – 0.202 % OF TOTAL
1923	0.08 – 0.16 " " "	0.2 – 0.2 " " "
1924	0.13 – 0.20 " " "	0.33 – 0.23 " " "
1925	0.4 – 0.7 " " "	1.1 – 0.9 " " "
1926	1.3 – 2.0 " " "	3.1 – 2.0 " " "
1927	1.5 – 2.6 " " "	4.7 – 3.6 " " "
1928	2.2 – 4.4 " " "	9.4 – 7.3 " " "

(A) THOUGH EXACT DATA FOR PERCENTAGE OF VENEZ. CRUDE CRACKED IN THE U. S. ARE NOT AVAILABLE, THE TRUE PERCENTAGES OF REFINED PRODUCTS ADDED TO U. S. SUPPLY ARE LIKELY TO BE FOR GASOLINE, NEARER THE LOWER LIMITS AND FOR GAS OIL AND FUEL OIL NEARER THE UPPER LIMITS ABOVE SHOWN.

enon of Venezuela's rise to high position, have endeavored to answer these questions, in the hope that they may help to clarify the current thought on the subject.

In the first place, it should be thoroughly understood that Venezuela's rapid rise has been in no way related to the so-called boom developments as we know them in the United States. Production in a comparatively few years has reached substantial proportions, but this has not been the result of any greatly accelerated and extravagant drilling campaign. The frequently expressed thought that the Venezuelan operators are indulging in a reckless and uncontrolled drilling fight for greater and greater production, is quite erroneous; and the imputed accusation that these producers, instead of coöperating with American curtailment programs, are taking advantage of the overproduction situation rapidly to broaden their markets, is only partly accurate, and when thoughtfully scrutinized presents little ground for criticism.

With respect to drilling, assuredly an important index of the oil industry, the statistics show that the number of rigs in operation in Venezuela during 1928 was only moderately greater than during 1927; the average for the past year being 85 rigs as against 76 in 1927, and 80 in 1926. Moreover, out of these figures, which are for the entire country, approximately 30 rigs were occupied with wildcat and semi-wildcat explorations, leaving only between 50 and 60 as the number actually working in the producing fields.

These figures portray a degree of moderation which is sharply emphasized when contrasted with the records of the various important oil-producing states in the United States. Table II shows this comparison for the past three years, the states and Venezuela being arranged in the order of their 1928 production. The small amount of drilling activity in Venezuela, compared with its production, is strikingly evident; and it will also be observed that even on the basis of percentage increase from year to year, Venezuela exhibits only an insignificant expansion in drilling activity, notwithstanding the fact that the exploitation of prolific new territory might well be expected to show a more rapid rate of acceleration during its early stages at least.

From the standpoint of the known resources and prospective oil reserves, Venezuelan operations could justifiably be conducted on a much larger scale. The area of the country, if superimposed on an equivalent territory in the United States, would cover the states of Texas, Oklahoma, Louisiana, and part of Kansas; and were such a geographical

TABLE II

AVERAGE NUMBER OF DRILLING RIGS IN ACTIVE OPERATION DURING THE PAST THREE YEARS

	1926	*1927*	*1928*
Texas	1,109	973	910
Oklahoma	1,129	1,046	715
California	422	404	511
Venezuela	80	76	85
Kansas	352	226	223
Arkansas	104	49	62

transposition possible, it is highly probable that the relative drilling activity within the areas so transposed would be vastly different.

To some extent, operations in Venezuela are held in check because of the natural disadvantages of the country,—tropical conditions, lack of transportation and adaptable labor, et cetera. The natural obstruction which prevents deep-sea tankers from taking on oil direct from points inside the lake and necessitates the shallow-draft lake tanker as an intermediate link in the transportation chain also operates as a general brake on the situation. However, all of these obstacles are merely incidental engineering problems, differing from those met with in American fields only in kind and degree, and are not the primary central factors bearing on the rate of drilling. In final analysis, the credit for holding the situation to its present size, instead of one of even larger proportions, must be attributed to the operators themselves; and in this regard it may be stated positively that the drilling restraint indicated by the foregoing figures is very largely a result of mutual curtailment agreement.

It is hardly to be supposed that the motives which prompted the Venezuelan producers to hold production to 106,000,000 barrels in 1928, and which give promise of holding the present year's output to less than 150,000,000 barrels, were inspired by any abstract feeling of altruism toward the whole oil industry. Indeed, it is doubtful if this motive has ever exerted appreciable influence in the petroleum world.

The logical explanation seems to be closely related to the fact that the Venezuelan operators are, after all, also Mid-Continent operators, and though in this latter field they do not enjoy, as in Venezuela, a full 100 per cent sovereignty, they do have a very substantial stake, one not lightly to be placed in jeopardy; and the disruption too rapidly of long established markets gives rise to many disagreeable repercussions that must be held in check, to avoid undue havoc with balance sheets.

Under such conditions, it becomes merely a matter of ordinary business judgment to pause and appraise the complex of new economic factors before pushing ahead too rapidly, and this seems to be what the Venezuelan operators were doing in 1928, and what they may be expected to continue doing until the situation clarifies, and their Mid-Continent interests are adjusted to the new order of things brought about by developments in Venezuela.

We now approach the crucial fact, which is the real essence of this entire situation, to wit, the new production from Venezuela, a large part of which comes on the United States market, arrives at a time when consumption plus exports is steadily falling behind production plus imports; thus it displaces a certain amount of domestic oil in such markets as it can economically reach.

This is a very condensed statement of a complicated situation. The qualifying phrase "that it can economically reach," is the key to the problem, and by elaboration of this we will reach the answer to one of the original questions, that is: "Who will suffer most as a result of Venezuelan oil?"

The "economic reach" of an oil territory is not a term of common usage. Possibly this is the first application of the words in this sense, and a definition may be in order. By "economic reach" we visualize a summation of various costs: operating, transportation, et cetera, which, acting as a sort of radius, traces a boundary around a given center of oil production, not a perfect circle, but a line which nowhere embraces territory in which the exchange value of crude oil as represented by the market for its constituent products is less than the sum represented by the radius. In other words, we recognize the existence of a logical market zone[1] surrounding each petroleum province. In times of great demand, relative scarcity, and consequent high price, the boundaries of these zones will expand to the point where the zonal limitations will disappear, or at least retain little of their character as obvious economic boundaries. When the reverse set of conditions prevails, the zonal radii will lose their erstwhile elasticity; they will take on definite magnitudes, and the boundary of the natural sphere of influence which any oil field may properly dominate will at length be sharply drawn as the true resultant of the economic forces involved.

The existence of these zones is nothing new. They have been with us since the beginning of the industry. In what we call "normal times,"

[1]The importance of "petroleum market zones" was first discussed by Michael O'Shaughnessy in *South American Oil Reports*, issue of February, 1928.

that is, when there are plenty of buyers for crude oil anywhere, and not too much to sell, these zone boundary limitations are practically effaced, but under even the most prosperous conditions the limits, though perhaps vague, can still be traced; thus, although perhaps few persons have considered the matter, it is a fact that the Mid-Continent field has never marketed much oil in California (lubricating oil perhaps, but none of the other products), nor has California, the Mid-Continent, or Pennsylvania, been an important factor, for example, in the Persian market.

Such cases could be multiplied indefinitely, but the point to be drawn from all of them is the same, namely, they are all examples of the limitation of market zones by the "economic reach" of the oil fields themselves.

As previously stated, these zones have always been in existence (similar zones exist in all industries), but heretofore they have been more or less neglected, due to various special factors, and the fortunate circumstance that during the first few decades of this very young industry's history prices have in general been so satisfactory that the incentive was lacking for speculation concerning theoretical limitations that had no dollars and cents significance. Thus, while we have carefully observed the ebb and flow of the industrial tide, and have accumulated plentiful records bearing on specific accomplishments, we have failed to study closely the concomitant phenomena of these oscillating market zone boundaries. Like the geometrical concept of parallel lines meeting at infinity, the oscillations of these zone boundaries were taking place in a sphere beyond the limits of our economic perception; hence, of what value the formulae that might express their variation?

Now, however, we face a situation fundamentally different from anything with which the oil industry has been confronted. Reduced to its simplest terms, it is a change from a market condition where supply of the commodity was the doubtful variable to a condition where the ability of the consumptive requirements to use the available supply is the unknown factor.

Any fundamental economic change must bring into play a train of new explanations and theories, in short, a new philosophy. Accordingly, we may well set about finding the terms with which the changed order of conditions may be expressed, and the new limits equated.

In going about this, we at once perceive that the question of economic zone boundaries assumes a position of great importance, and in fact seems to be about the only important new variable bearing on the changed conditions. The oscillations of the zone boundaries being now

within our comprehension, the nature and behavior of these phenomena become at once fitting subjects for analysis.

As time goes on, the investigation of these economic zone boundaries, and the economic reach of a given oil region, will probably assume an increasingly important place in the literature. For the present, a very brief statement of the conception will suffice to support the conclusions toward which this discussion is leading.

In examining the general subject of economic market zones, we recognize the following principal variable, namely, the boundary of the zone itself. This unstable line expands and contracts, or oscillates back and forth in obedience to innumerable changing conditions among which may be noted the following:

a. The discovery of important oil resources in a new locality
b. The rise or decline of available supplies in any oil region
c. The rise or fall of production costs in any oil-producing region
d. The rise or fall of transportation rates between widely separated areas
e. A miscellaneous complex of factors including the general question of the various sources of motor fuel other than petroleum; their geographic distribution, and progress toward economic importance

It would perhaps be convenient for any particular problem if these variables could be assigned specific values and equated in such a manner as to yield a mathematical expression for the economic market zone boundary line that could be applied generally. Obviously, however, the numerous combinations that may arise from the interrelationship of these variables precludes any such simple solution.

In general, the positions of the economic zone boundaries will work themselves out by cut-and-try methods. Even a perfectly sound theoretical proof, for example that Salt Creek crude can not be economically marketed in Trinidad, would hardly be accepted without a practical demonstration.

Let us now examine in the light of the foregoing brief theoretical background, the fact that major oil resources have been made available in a section of the earth's surface that can be geographically described as the area lying between 2° and 12° north latitude, and 60° and 73° west longitude, or, politically, as the Republic of Venezuela.

First, it is obvious that the development of this oil territory sets up a new market zone tributary to it. This in turn means that certain other market zone boundaries must accommodate themselves to the new force, and brings us to the specific problem, which is the determination of this new zone boundary, the resultant of the new Venezuelan oil, and the resistance to it of oil from older producing regions.

Speaking very broadly, there were in the United States, until two or three years ago, but two recognizable market zones: (1)the Pacific states, western Canada, and the Orient tributary to California; and (2) the balance of the country, tributary normally to the Mid-Continent and other lesser fields, but absorbing, when need arose, the surplus from the California zone also.

With the increase in available supply with respect to the demand, the price level has assumed a downward trend, and this in general has narrowed profits. There are exceptions, of course, to all trends, and thus specific properties embracing exceptionally prolific oil reserves and enjoying exceptionally low costs, will not be affected as much as the less fortunate majority. In general, however, the tendency during a period of plentiful supply must be a contraction of the economic reach of any given oil field, as, with prices declining and costs fixed, the only source from which profits may be obtained will be from savings in the transportation spread between producer and consumer.

These general forces of domestic oversupply, together with the particular new force exerted by Venezuelan production, are giving rise to the re-shaping and splitting up of the old zones into new market areas logically tributary to the most economically available crude oil source.

It must be evident that when a market realignment is brought about by the factors just mentioned, the zone of greatest competition will be in territory which consumes the surpluses from oil regions located at a distance and on which more than one such surplus depends for its outlet. The outstanding example of such a territory in the United States is the Atlantic seaboard. Here only a negligible percentage of the consumption is supplied by the local production. The balance comes from many sources: the Mid-Continent, California, Mexico, Texas, and now Colombia and Venezuela.

From the standpoint of transportation rates, and cost of production, Venezuelan oil enjoys a decided advantage in the Atlantic states markets over any other oil except

a. Oil from prolific Gulf Coast fields
b. Low-cost oil from Mexico
c. Very low-cost oil from West Texas
d. Very low-cost oil from prolific fields elsewhere in the Mid-Continent
e. Very low-cost oil from California

Groups *a* and *b* are natural competitors of Venezuela for the Atlantic states market, transportation rates and production costs being about the same.

West Texas production is in part very low-cost oil, and in spite of the 55-cent charge for bringing it to the Gulf Coast, can compete on a fairly even basis with Venezuela in the Atlantic states, both showing fair profits when laid down north of Hatteras for $1.20 a barrel.

Groups *d* and *e* are not ordinarily logical competitors with Venezuela except in so far as their lighter gravity and more desirable refining qualities may compensate for the transportation disadvantage; but there are always a few exceptionally low-cost properties in California and the Mid-Continent which can stand comparison with Venezuela, or even show better records. As these properties, however, comprise only a small percentage of the Mid-Continent and California reserves, the bulk of the oil from these territories could be, with further price declines, completely excluded from the Atlantic states market, at least in so far as this market can be supplied by Mexico, Venezuela, other South American countries, the Gulf Coast, and West Texas.

The most illogical participant in the Atlantic seaboard market would seem to be California, and it is doubtful if this state will be an important factor in the East for many years longer, though there may be several severe periods of dumping before its market zone limit is finally pushed west of the Rockies. Unless the Atlantic states crude market price falls to a very much lower level, however, there will probably always be some California oil, and especially gasoline, that can stand the high transportation cost into the eastern market, and perhaps the complete disappearance of this trade is not to be expected.

West Texas, so long as it can furnish fields of the Yates and Hendricks type, can force its production into almost any market it chooses outside of perhaps the normal California zone and certain export markets far afield. The resistance to the spread of this oil into the central states, however, will be so strong that probably by far the most of it will seek a market outlet in the East by way of the Gulf and tanker transportation from there.

Considering, then, these various factors with reference to the new market picture that seems to be in process of evolution, we recognize the following well defined tendencies:

1. An increased participation in the eastern territory from the Gulf Coast, Venezuela, and West Texas.

2. A dwindling supply of California oil on the Atlantic Coast, and a rather sharp withdrawal therefrom of the higher-cost Mid-Continent products.

It appears that every measurable factor, of which Venezuela is only one, tends to the conclusion that Mid-Continent production must even-

tually relinquish a large part of its Atlantic seaboard market. Approximately the market zone limits for Oklahoma, Kansas, north-central Texas, north Louisiana, and Arkansas, that is, the true Mid-Continent field, will include the Mississippi states, and in general the territory between the Rockies and the Alleghenies.

This is not as big a market as the Mid-Continent formerly enjoyed, and in the readjustment to these new limits there is bound to be some hardship. How serious the effects of the change, will depend in large degree on the extent to which operators comprehend the nature of the economic forces arrayed against them, and, comprehending, refrain from a futile and expensive struggle against an inevitable situation, which, whether or not it turns out to be permanent, is a condition now at hand, with prospects that it will endure for a few years, at least.

It is hardly within the scope of this article to point to the course by which Mid-Continent producers can minimize the loss that will result from the previously mentioned changes. Briefly, however, it is our opinion that the final result will be actually beneficial.

Two factors stand out as safeguards against any serious disintegration of the Mid-Continent situation.

1. The era of low prices now in prospect will in all probability force the consummation of a number of economically sound mergers that should go a long way toward erasing many of the competitive boundary lines that are now partially responsible for excess production.

2. The majority of producers will in time come to realize, or perhaps be forced to a realization, that after all they are in business to make a profit, and that under some circumstances, this purpose is not solely dependent on volume of output. They will then commence to consider the oil underlying the Mid-Continent fields in its true light, as a great asset in which each has an interest in keeping more or less with his size. In other words, they will look on the Mid-Continent oil reserve as a business in which they are shareholders, rather than players in a lottery.

There is just so much of this oil, however many billions of barrels that amount may be, but from the standpoint of profits every other consideration falls into insignificance when compared with one factor,—the time element, or rate at which it is sold.

The thought that these billions of barrels of oil, a "one time crop" as it has been so aptly described, will go to the use of society without adequate compensation for the industry rendering the service, is highly improbable. When it is fully comprehended that a slowing-up in the present speed by only 10-20 per cent will change this big reserve from a

losing proposition to a source of substantial profit, there should come about a more sound economic outlook, and with it a return to satisfactory profits.

In the final analysis, however, the greatest source of hope for the Mid-Continent producers lies in the direction of consolidation. Not a combination of two 10,000-barrel-a-day companies, so that together they can do 20,000 or more, but a combination of interests on such a basis that the increase in equity value of the reserves resulting from the combination will more than offset a forced decrease in production. This, incidentally, is a sort of theoretical formula which all oil company merger projects may well have in mind as their guiding principle.

The obstacles standing in the way of a widespread series of combinations in the Mid-Continent are chiefly two:

1. Fear on the part of small operators concerning the wisdom of trading leases and wells for shares in enterprises which they will no longer dominate, and

2. Personal feelings of managements with respect to the distribution of control after the consolidation is effected.

Neither of these obstacles will long endure against a period of real hard times. The first objection can be shown to be very unsound in principle, as the small producing property actually (under present conditions) becomes more valuable when joined to a larger unit. The oil of the combined property will be sold deliberately, and at a rate calculated to yield the best price, a policy ordinarily impracticable for the small unit. This increment of value added to properties going into a soundly conceived consolidation is similar to the so-called "plottage value" in real estate; thus, two adjacent 25-foot lots on Fifth Avenue are worth more taken together than the combined value of two separated lots of equal area.

Where fair terms prevail, there should be little difficulty during the present year in working out a number of very beneficial Mid-Continent consolidations, both large and small.

So far as the second obstacle goes, it will require but a brief period of operating losses to arouse the financial elements upon which the oil industry rests to a full appreciation of the situation, and the development of a line of action in which there will be small room for considerations of a personal nature. When once sufficiently alive to the problem, the controlling forces have, we believe, sagacity and resources sufficient to restore the Mid-Continent oil business to a sound paying basis, with comparatively little loss of time, and this solely through the applica-

tion of time-tested business expedients,—not through the agency of legislation, or outside artificial help.

One of the original questions listed for consideration in the fore part of the discussion was "What can be done to prevent all this?" It will be observed from the assured manner in which the changed marketing situation has, in the foregoing discussion, been predicted, that the writers can have but little thought for the appearance of any development that might change the situation.

Such is indeed the case. We are cognizant of the agitation for a tariff against Venezuelan oil. There is probably much to be said on both sides of this question, but it is believed that the final decision will rest on the point that so far as the Mid-Continent is concerned, if it is not Venezuela, it will be West Texas and California that will ultimately curtail its influence in the Atlantic states market; and with the advent of a tariff that would accentuate this purely domestic struggle on the one hand, the export business of the country would suffer to such an extent that markets would be tightened as much as though the pressure of the Venezuelan oil were being directly thrown into the situation, as at present. A tariff plus the program of consolidation already recommended would undoubtedly bring about at least a temporary condition of prosperity, as the domestic market, if not over-supplied, would support a very prosperous industry. There are, however, it is thought, many valid objections to a tariff which would seem almost certainly to prevent its employment in this case. (1) The rights of the consumer would probably in this instance receive more legislative sympathy than is generally the fact, and (2) the question is involved with considerations of national safety which are not consistent with legislation that would hasten the exhaustion of our domestic petroleum reserve. Whether it would yield the highest return in dividends to the oil industry or not, a tariff on oil seems to the authors to be a solution hopeless of attainment.

Without the application of some artificial force (tariffs, excessive export taxation, and the like), production from Venezuela will probably increase until it becomes the principal source of raw material for Atlantic Coast refineries. This seems inevitable, for, with the exception of the occasional domestic property enjoying some special low-cost advantage, Venezuela can on the average produce and deliver crude oil to Atlantic ports for less money than any other region. It must as a natural consequence secure a large percentage of the available Atlantic states business, if it can supply the volume.

The situation in the field indicates that further increase in output over the present rate is justified in view of the large reserves already

proved. Against this incentive to rapid expansion is the certainty that an uncontrolled flood of Venezuelan oil will add to the demoralization of the market, and even Venezuelan oil can not return a profit if it has to compete with distress liquidation. Accordingly, it looks to us as though the rate of increase for the next few years will be steady, but much more moderate than it has been in the past. As against 67 per cent increase for 1928 over 1927, we look for considerably less than 50 per cent increase in 1929 over 1928, and less than 30 per cent increase in 1930 over 1929. By 1932, or thereabouts, production should be fairly stabilized at approximately 600,000 barrels a day. Thereafter growth should be slower, as the market zone logically tributary to the Venezuelan fields, which includes the Atlantic states and western Europe, could hardly absorb oil from this one source at a much more rapid rate, considering the certainty that competition from other sources will always be present.

The final question of the series which we originally set out to answer was: "How serious will the consequences of all this be?" This has already been covered by inference in the discussion of the effects presently to be felt in the Mid-Continent field. To be specific on this point, though at the expense of some repetition, it appears to the writers that the net result, over a fairly long period, will not be detrimental to Mid-Continent prosperity. The very obviousness of the situation may force, more quickly than otherwise might occur, the adoption of protective defenses along the line indicated. If, then, the period of futile struggle for illogical markets with high-cost oil against low-cost oil is cut short, a genuine benefit will have been rendered. In this case the Mid-Continent oil, after withdrawing from its unequal competition, may be supplied at a rational rate to its normal geographic and economic market; and this should mean in the end a much larger ultimate profit on the Mid-Continent oil reserve viewed as a whole.

With this rather optimistic view of the situation, we complete the discussion of the original questions. Lest the space required to achieve this end, however, may to some extent have obscured the conclusions reached, it seems fitting to offer a brief summary which, condensed as much as possible, follows.

1. Venezuela has vast reserves comparable with those of our leading oil states.

2. Because of favorable geographic position and low production costs, it is inevitable that Venezuela ultimately will obtain a very large share of the Atlantic states business.

3. Venezuela's fairly rapid growth may be expected to continue until it reaches about 600,000 barrels a day by 1932. Beyond this point market resistance will probably hold expansion in check.

4. The combination of Venezuela, West Texas, and the Gulf Coast, with periodic pressure from California, will probably force a large volume of high-cost Mid-Continent oil out of the Atlantic states market.

5. It is believed that neither tariffs nor any other artificial obstacle can stay the spread of Venezuelan oil into the markets it can supply most cheaply.

6. The result should be to hasten the rationalization of Mid-Continent production to dimensions consistent with consumption within its own logical market zone. This market, after all, is one of splendid proportions, and sufficient, if properly handled, to yield a satisfactory profit to all concerned.

GEOLOGICAL NOTES

GRAPHIC SOLUTION OF STRIKE AND DIP FROM TWO ANGULAR COMPONENTS

In strata where strike and dip components only can be observed, any two may be readily reduced graphically to strike and dip. Thus, if N. 20° E., + 3° 40′ and S. 60° E., − 4° be the bearing and vertical angle respectively of two observed strike and dip components on a single bed, the computed strike is N. 66° E. and the dip 5° SE.

This result is obtained as follows.

On a sheet of the field notebook, lay off the meridian NS. (Fig. 1).

Convert the observed bearings to the proper quadrant for negative vertical angles, that is, S. 20° W., − 3° 40′ and S. 60° E., − 4°.

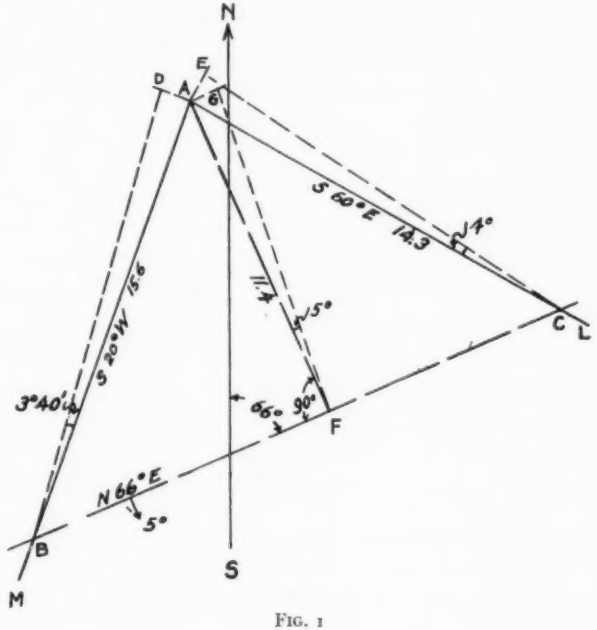


FIG. 1

From any convenient point A lay off with a protractor the lines AM and AL with the bearings S. 20° W. and S. 60° E., respectively.

At A draw perpendiculars to AM and AL with the protractor and on each lay off equal distances AD and AE, any convenient length being used, depending upon the arc of the least vertical angle, using a scale or compass.

From D lay off a line at the angle 3° 40′ to AM and intersecting AM at B. From E lay off a line making an angle of 4° to AL and intersecting this line at C. Where the vertical angles are small, greater accuracy in platting is obtained by computing the bearings of DB and EC and laying off these angles from NS.

Draw BC, which is the line of strike, and with the protractor measure its acute angle from the meridian NS. The correctness of this operation becomes evident if we imagine the triangles ABD and ACE to be rotated about the lines AB and AC, respectively, until their planes are at right angles to, and above, the horizontal plane of the paper.

Draw AF perpendicular to BC with the protractor.

At A draw a line perpendicular to AF and lay off AG equal to AD. Draw FG. Then angle AFG is the true angle of dip, which may be scaled with the protractor. This becomes apparent if we rotate triangle AFE about the line AF to a plane at right angles to, and above, the plane of the paper.

Where the vertical angles of the components are small, a more accurate method, as well as a more simple one, is to lay off the natural cotangents of the vertical angles along the lines AM and AL respectively, to the same scale, thus locating the points B and C without drawing the perpendiculars AD, AE, and AG, or platting the vertical angles. Then draw BC and AF perpendicular to BC. Any scale may be used convenient to the size of the page and the cotangent of the least vertical angle. This becomes readily apparent upon inspection with a little practice.

Thus the natural cotangent of 3° 40′ is 15.6; that of 4° is 14.3. Therefore, scale off AB equal to 15.6 and AC equal to 14.3. With the same scale measure AF, which in this case is 11.4. This figure corresponds with the natural cotangent of the angle of dip and, as may be readily determined from the tables, is 5°.

Since vertical angles may, with proper care and use of the Brunton, be read to the nearest fifteen minutes of arc, multiple readings may be averaged to the nearest ten minutes of arc, when sighting small angles over long distances; and a table of natural trigonometric functions to

the nearest ten minutes of arc is sufficient. Such a table is published by Lefax on a single sheet conveniently inserted in the field notebook.

H. W. KITSON
Research geologist, The Texas Company

LOS ANGELES, CALIFORNIA
July 21, 1929

CORRELATIVES OF MOHAWKIAN SEDIMENTS IN KANSAS

The writer has attended the field conferences of the Kansas Geological Society of the last two years, at which meetings he has presented facts and suggestions about the stratigraphy of Mohawkian formations, and has distributed tentative correlations based on preliminary studies of the formations. There has been published recently in this *Bulletin* a chart that incorporates these tentative correlations;[2] there is no statement as to their origin. Inasmuch as more thorough studies have revealed errors in the preliminary correlations, it is deemed advisable that there be presented a table depicting the relations of the beds as now interpreted. The general discussion of the correlations, as well as definitions of certain formations, has been presented.[3]

In the compilation of the Chazyan correlations, recourse has been made to publications of Ulrich[4] and of Dake.[5] The limited faunules found in Kansas wells make it hazardous to propose precise correlations of certain of the beds there with formations in other regions. That there are beds in Kansas equivalent in age to the Spechts Ferry member of the Decorah formation in Iowa is very probable. But it is improbable that all of the fossiliferous shaly "Decorah" beds of Kansas are of Spechts Ferry age. Nearly all the fossils listed from Kansas are present in the Spechts Ferry member; but they occur not only in the Spechts Ferry but in older and younger beds.

Raymond[6] has correlated the top of the Prosser limestone of the Galena with the Upper Cobourg; he correlates the Stewartville and

[2]F. C. Edson, "Pre-Mississippian Sediments in Central Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 5 (May, 1929), p. 457.

[3]G. Marshall Kay, "Stratigraphy of the Decorah Formation," *Jour. Geol.*, Vol. 37 (1929), in press.

[4]E. O. Ulrich, "Geology of the Thousand Islands Region," *New York State Mus. Bull. 145* (1907), p. 78.

[5]C. L. Dake, "Problem of the St. Peter Sandstone," *Univ. Missouri Sch. Mines Metall. Bull.*, Vol. 6, No. 1 (1921), p. 219, et cetera.

[6]P. E. Raymond, "Correlation of Ordovician Strata of the Baltic Basin with those of Eastern North America," *Bull. Mus. Comp. Zoöl. Harvard*, Vol. 56, No. 3 (1916), p. 257.

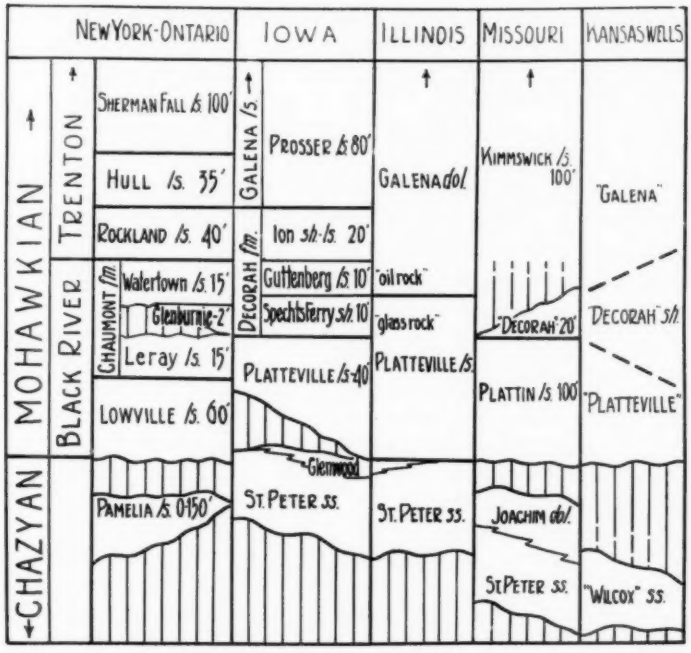


FIG. 1.—Correlation table of formations correlated with lower Mohawkian sediments in Kansas wells. Thicknesses shown in feet.

Collingwood on the basis of stratigraphic positions. Ulrich[1] has correlated the top of the Prosser with older beds in the Trenton group.

G. MARSHALL KAY

COLUMBIA UNIVERSITY
NEW YORK, N. Y.
July 25, 1929

FISK, OR SHIELDS, POOL, COLEMAN COUNTY, TEXAS

The Fisk pool is 10 miles south of Coleman, Coleman County, Texas. It was leased by the Taylor-Link Oil Company in December, 1927, on the basis of geology mapped by Melvin James Collins, who is now employed by the Douglas Oil Company of San Angelo, Texas.

[1]E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. Amer.*, Vol. 22 (1911), pp. 524-25.

The structure was mapped on a limestone bed capping the hills and mesas in this area. The outcropping formation of this area is the very top of the Cisco series of Pennsylvanian age, by some geologists referred to as the Putnam formation.

The discovery well was drilled on a location as recommended by Collins in the SW. corner of the NE. ¼ of Section 105, Mollie Barker land. It topped the Babbington sand at 681 feet on June 3, 1929, and made 200 barrels of 43° gravity oil daily. Besides the producing formation there are several deeper possibilities.

ROBERT H. DURWARD

MIDLAND, TEXAS
August 2, 1929

STATE OF SÃO PAULO, BRAZIL

The "Commissão Geographica e Geologica" of the State of São Paulo has recently published a geological map, by Florence and Pacheco, printed in nine color patterns, conforming to the international convention. The map is on a scale of 1 to 1,000,000 or 10 kilometers per centimeter and represents an area of 248,000 square kilometers.

A reduced copy of this map in colors and on a scale of 1 to 2,000,000 will appear as an illustration in a book by this writer on *The Geology and Oil Prospects of the State of São Paulo*, which will be published shortly in both Portuguese and English, by the State Government.

The writer considers it the best map published of such a large area in South America. It represents practically the life work of Dr. Guilherme Florence and Dr. Joviano Pacheco, geologists of the São Paulo Commission of Geography and Geology.

The formations represented are: (1) the metamorphic complex of Archean and possibly early Paleozoic metamorphic and igneous rocks; (2) the Faxina sandstone of Devonian age; (3) the Itararé formation (Glacial) and (4) the Tatuhy formation, both of Carboniferous age; (5) the Carumbatahy formation, mostly marine, including the marine Iraty oil shale at its base, both of Permian age; (6) the mainly aeolian Botucatú sandstone, including the fluviatile and aeolian Piramboia formation at its base, of Triassic and possibly in part of Jurassic age. At the top of this formation lie the great sheets of basalt (Jurassic?) with a thickness of approximately 1,000 feet, which underlie most of the western part of the state; (7) the Cayuá formation of wind-blown sand of Jurassic(?) age, which was discovered last year in the course of

the present investigation and which covers much of the lava; (8) the Taubaté formation of late Tertiary age. Pleistocene and recent deposits are not shown.

Points of main interest to the oil geologist are the numerous indications of oil and gas in the Iraty shale of Permian age and in the overlying sandstone of the Piramboia formation (Triassic). These are of heavy black asphaltic oil, that originated probably in the Iraty shale. In the Itararé formation (Glacial) showings of light paraffin oil have been found in two wells. The only probable source for this light oil that the writer can conceive is in hypothetical Devonian black shales beneath the Glacial formation under the central part of the Paraná Basin. These shales do not crop out within the state of São Paulo and, if present, they must be truncated and overlapped by the Glacial formation, in the same way that the underlying Devonian sandstone is truncated in the southwestern part of the state, between Faxina and Itararé. A little of the Devonian shale shows in northeastern Paraná, about 100 kilometers farther south, but there is no large outcrop of it nearer than the foothills of the Andes in Bolivia, about 1,200 kilometers farther west, or 700 kilometers west of the western margin of the Paraná Basin. The Devonian shales are regarded as the probable source of the light oil in the wells of eastern Bolivia.

The structure of the state is simple, consisting essentially of a monocline, dipping northwest or west at a rate ranging from 1 to 20 meters per kilometer. The oldest formation lies on the southeast along the sea coast, and is followed in regular succession by progressively younger formations toward the northwest.

A large normal fault, upthrown on the northwest, follows the seacoast. A similar fault, also upthrown on the northwest, makes the Parahyba Valley, in which the late Tertiary and early Pleistocene clays and sands were deposited. This fault creates the line of communication by rail or automobile from Rio to São Paulo. In the sedimentary area of the state faults are rare and very small, none being large enough to show on a map of this scale. The anticlines are mostly of the plains type, being small and mostly of low dip. One of the highest anticlines observed is that on the "fazenda" (ranch) Bôa Esperança, near Piracicaba, where the State is now drilling a deep well. On this anticline the dips in places are as steep as 25°. Other anticlines were found in which the dip was locally as steep as 12°, but more commonly dips are to be measured in a few meters per kilometer. Geological work in this region is rendered very difficult by the deep weathering of the rocks, there being no natural

outcrops of any but the most resistant strata, and these not being common. A geologist should allow many months to become acquainted with the character of the soils produced by the weathering of the different formations before he can expect to do accurate field work here. Only in the dry season, from about April or June to October or November, is it possible to do good work.

CHESTER W. WASHBURNE

SÃO PAULO, BRAZIL
July 23, 1929

DISCUSSION

ORIGIN OF POROSITY IN REEF LIMESTONE OR DOLOMITE

In a discussion of porosity in the Lea-Winkler County area Robin Willis[1] states that there is a definite connection between reef barriers and porosity. The writer is quoted as having "pointed out how porosity is formed in the reef itself by dolomitization of the original calcite of the reef." The writer has made no original study of the processes or results of dolomitization. Statements made by him regarding the probable origin of dolomite and the effect of dolomitization in the destruction of organic remains[2] were made on the authority of others with appropriate references. It is a well known fact that if half the molecules of calcium carbonate in calcite were replaced by magnesium carbonate a reduction in volume would result. There appears, however, to be little authority for the assumption that the process of dolomitization is so simple as this.

The writer does not hold to the view that porosity in reef rocks is caused by dolomitization of calcite and must therefore take exception to the above quotation.

E. Russell Lloyd

Midland, Texas
August 17, 1929

[1]"Structural Development and Oil Accumulation in Texas Permian," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), p. 1040.

[2]E. Russell Lloyd, "Capitan Limestone and Associated Formations of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), p. 647.

RESEARCH NOTES

A. A. P. G. RESEARCH COMMITTEE

(Members' terms expire immediately after annual Association meetings of the years shown)

ALEX W. McCOY, *chairman*, 919 East Grand Avenue, Ponca City, Okla.

1930:
D. C. BARTON, Petroleum Bldg., Houston, Tex.
R. C. MOORE, Univ. of Kansas, Lawrence, Kan.
W. T. THOM, JR., Princeton Univ., Princeton, N. J.
F. M. VAN TUYL, School of Mines, Golden, Colo.

1931:
K. C. HEALD, 1161 Frick Bldg. Annex, Pittsburgh, Pa.
F. H. LAHEE, Box 953, Dallas, Tex.
M. K. READ, 1519 Linda Rosa, Los Angeles, Calif.
F. B. PLUMMER, Bur. Econ. Geology, Austin, Tex.

1932:
C. R. FETTKE, 1118 Wightman, Pittsburgh, Pa.
A. I. LEVORSEN, Box 1830, Tulsa, Okla.
SIDNEY POWERS, Box 2022, Tulsa, Okla.
R. D. REED, 1717 South Third, Alhambra, Calif.
L. C. SNIDER, 60 Wall Street, New York, N. Y.
W. C. SPOONER, Box 1195, Shreveport, La.
W. E. WRATHER, 4300 Overhill Dr., Dallas, Tex.

The purpose of the Research Committee is the advancement of research within the field of petroleum geology. If members working actively in research on particular problems care to register with the Research Committee, the committee will be glad to aid them in any way it can and put them in touch with other men who are, or have been, working on similar or allied problems and can perhaps effect some integration of the research work of the Association. If the younger, or older, members of the Association, who are doing or preparing research for publication, will come to any member of the Committee, he will be very glad to offer whatever advice, counsel, or criticism he can in regard to the research, its prosecution, or its preparation for formal presentation. The Committee would be glad to have members formulate and present to it suggestions in regard to research problems and programs.

REMARKS ON RECENT RESEARCH WORK ON THE GENESIS OF PETROLEUM

A great deal of very interesting research work has been performed these last three years regarding the vexing problem of the genesis of mineral oils and gases, as we encounter them in our oil pools.

It is generally recognized that the oil and gas in the present oil sands are secondary accumulations of the fossil hydrocarbons which originated in some neighboring location and were subsequently concentrated in a suitably porous reservoir, the structure of which was favorable to such accumulation.

There is a widespread belief (which, however, is yet only a theory) that the source is in certain *sediments*, containing a sufficiently large admixture of fossil organic matter—bitumen. The most conspicuous of such bituminous rocks are the so-called "oil shales," which indeed yield considerable quantities of petroleum-like oils on distillation. They occur in vast deposits in numerous geologic formations and localities.

Until recently, practically all research work regarding the origin of petroleum, including gas, has been concentrated on such oil shales. Many scientists have subjected them to a number of tests, chemical as well as physical, to try to find the process by which the bitumens contained in them could have been converted into the oils and gases of our oil pools.

Are we sure, however, that these oil shales are a primary source rock of our oil fields? *Far from it!* On the contrary, there is good reason to believe that they are not. So far, not a single oil pool of commercial importance has been discovered, anywhere in the world, clearly connected with an oil-shale deposit. Oil shales can indeed be converted into oils, closely related to natural crude petroleum, by artificial distillation, but in nature this change does not seem to occur; and it does not result from pressure, shearing, or other deformation processes. Exploration of the oil-shale regions for commercial deposits of liquid petroleum was as devoid of success as the laboratory experiments, which tried to imitate as closely as possible the natural conditions that might have caused conversion.

This *Bulletin* recently published (April, 1929) two interesting papers by J. E. Hawley on the possible generation of oil in rocks by shearing pressures; it contains a good summary of former work on this problem, which since 1926 has been the problem of Research Project No. 1 of the A. P. I. research foundation. Like his predecessors Hawley worked exclusively on typical oil shales. The results are negative: temperature seems the only agent able to produce oil from oil shales, and even this does not seem to bring about this result in nature.

Thus there are grave reasons to believe that the typical oil shales are not the primary source of mineral oil and that, consequently, research work in the laboratory and practical exploration in the field, based exclusively upon the presumable connection between oil shales and oil pools, will in all probability continue to be a disappointment.

Geology has long recognized *another possible source rock*, namely, certain marine shales, which indeed we regularly find in close proximity to our oil and gas pools. These are far less bituminous than oil shales, but they give evidence of containing considerable fossil organic matter, and also yield oils and gases on distillation, though far less, and not in sufficient quantities to consider such rocks as raw material for the commercial manufacture of petroleum products.

These shales are of *marine* origin. We also find marine limestones which are primarily bituminous. These rocks contain the fossil remains of marine organisms, largely microscopic plankton forms.

The typical oil shales, however, are deposits of land-locked lakes and swamps. Many were of very large dimensions, of the order of our present Great Lakes, but they were *lakes*, with no open connection with the sea, though the water need not have been fresh, but may occasionally have been salty, as in so many of our present lakes in arid regions.[1]

[1]The water in the basin in which the Colorado oil shales were laid down must, at least temporarily, have been decidedly salty. David White, in a letter to the writer (May 4, 1928) stated that material at Columbia, collected in the Green River deposits, more than 40 years ago, by J. S. Newberry, contains actual salts. Bradley and others have reported pseudomorphs of various salts.

The fossil remains in these shales are not marine, but of vegetable and animal débris and organisms, also largely microscopic, of the continental land areas.

By no means every marine shale, however, is bituminous. We find that this is the fact only with certain local sediments and only in certain beds. The majority of the marine shales of all geologic formations contain no primary organic matter at all, or far too little to give them any consideration as a possible source rock for our oil deposits.

The suggestive fact, however, is that these organic marine shales (and some similarly organic limestones), are regularly found associated with oil pools. A. W. McCoy has studied marine shales from many localities and geologic formations in the Denver laboratory of the former Marland Oil Company of Colorado; he determined their organic content by retort distillation, and proved that such bituminous shales are regularly present in a sequence of beds, connected with major oil pools.

Hence there is at least good reason for the belief that the source from which the oil and gas were primarily derived, by whatever natural process this may have happened, is in *certain organic marine shales (and limestones), rather than in the oil shales.*

The deposition of the sediments of former periods in the earth's history which the geologist studies, was a process in no way materially different from what occurs at present. Conditions and environment may, indeed, have differed, but the actual process was the same as it is to-day. There is no better way to try to understand fossil sediments than by the observation of the process of sedimentation as it goes on to-day and the study of the resulting recent deposits.

The research work of the A. P. I. project No. 4 is to approach the problem of the nature of fossil source rocks of petroleum by the study of the nature and deposition of similar sediments to-day in our present seas.

Dr. Trask found that, indeed, such deposits occur. They are not numerous and are confined to restricted areas, but this was also true in former geologic epochs: then also the majority of the marine deposits did not contain organic material. Their frequency may have varied from one period to another as general conditions varied on the earth, but richly organic marine deposits were always more the exception than the rule.

So far, we have found four areas around the North American continent where such organic bottom-sediments are now forming. They are the muds in Pamlico Sound, certain lime oozes off the Florida coast and in sheltered regions around Cuba, the muds of Maracaibo Bay, and certain muds off the southwest coast of California between the Channel Islands and the main land. All other coastal deposits of the North American seas are for all practical purposes barren.

In organic content the recent deposits cited compare well with those fossil bituminous marine shales and limestones which we find associated with our oil pools, and the oils and gases these recent muds yield on distillation are strikingly similar to those we obtain from fossil sediments.[1]

[1]For details see the publications of Parker D. Trask in this *Bulletin*, Vol. 11 (1927), pp. 1221-30; Vol. 12 (1928), pp. 556-57 and 1057-68.

Large quantities, amounting to hundreds of pounds, have now been collected from a selected few of these recent organic muds. The organic matter contained therein is being closely studied chemically, physically, and biologically. Seemingly equivalent fossil deposits are subjected to similar tests and the results compared.

It would seem to me that, interesting and valuable as is the research work on oil shales, it is a mistake to concentrate on them so exclusively as has been done and that we should first try to make sure that we are working on the real source rock of petroleum, when we engage upon the problem of determining how the solid organic matter contained in these sediments may have been converted into our mineral oils and gases. As, in fact, it seems ever more improbable that oil shales constitute the source of petroleum, we should concentrate on the problem of conversion of other material that seems to be more promising.

This *conversion problem* meets us everywhere. The recent material which Trask has analysed so far, indicates that none of these muds and lime oozes now contains organic matter more or less identical with mineral oils and gases. The percentage that can be extracted by solvents is infinitesimal. This is also true for bituminous marine rocks associated with our oil fields, also for oil shales. If, therefore, the recent muds, which Trask is studying, are the future source rocks, some subsequent natural process must convert the present organic matter into the hydrocarbons we call petroleum. If the marine rocks, associated with the beds in an oil pool, are the source of the oil, such conversion must have taken place or still be taking place.

In these fossil marine shales and limestones we still find unconverted organic compounds. So the question arises whether this is a still unconverted residue, and the oil and gas are derived from *another* part of the original organic content. If not, we would be on the wrong track, and not yet have found the real source of the oil.

We may be able to determine whether the organic residue now left is an unconvertible residue, different in nature from some other constituent that has already been converted, or whether the remaining organic material may, at some future date and through the further action of the required process, continue to yield crops of mineral oils and gases to migrate into the reservoirs. In other words, have we only one group of primary convertible fossil bitumens, or two or more (we might call them bitumens A, B, C. . .), of which some are refractory toward natural processes and remain unchanged (as seemingly the kerogens in the oil shales), while others are the real source of petroleum?

We shall have to determine whether the chemical nature of the marine—fossil as well as recent—organic matter, or at least part of it, is different from that in continental oil shales (of which we have also found a seemingly recent equivalent in the mud of certain algal lakes in Florida).

If the marine muds constitute a source rock, and the much more bituminous lacustrine muds do not, there must be a reason for this difference. It may be that the possibly inconvertible organic matter in the marine shales is of the same chemical nature, or at least in the same group, as the kerogens contained in oil shales.

If we really have found the recent equivalents of both kinds of fossil deposits, their changes in the course of progressive fossilization can be investi-

gated and we may be able to determine whether, under certain conditions, in the course of this process, oils and gases are being liberated which can migrate and accumulate in suitable reservoirs.

When we distill a bituminous rock or a recent organic sediment, we obtain only part of the organic matter present, probably not more than 20-25 per cent. The balance is either left behind as carbonaceous coke, or escapes as gases.

I am beginning to suspect that the real source of the mineral oils is only one group out of several groups of organic compounds, laid down in sediments. If the oil is able to migrate through considerable distances toward its final reservoirs, as the writer is inclined more and more to believe it can, a comparatively small percentage in the primary source rocks would suffice to make very large accumulations out of the enormous bulk of such more or less organic rocks.

It may be extremely difficult to isolate and even to distinguish such groups of fossilized organic compounds chemically; it might well be that it will be possible to distinguish them by their physical properties before they can be distinguished chemically. (It is the same with the vitamins.)

What I wish especially to call attention to, however, is that it is possible that the refractory kerogens are not a source material, but that we must look for the source among those compounds which are separated as volatile matter and permanent gases early in the process of distillation, and even when merely drying recent organic sea mud,

Such hydrocarbon gases can be reduced to compounds richer in carbon and less volatile, and it is possible that this is nature's process, rather than the process of slow distillation and cracking of solid hydrocarbons. We already know that radioactive bombardment can accomplish this result. Radioactivity is more or less omnipresent in the rocks, and the helium gases of the oil fields are also an indication of it.

This may be only one of the processes; there may be other agencies coöperating toward a similar result. Catalysis may be a factor, particularly in these finely porous shales with enormous active surface factors and, no doubt, enormous adhesion pressures in the adsorbed gases.

All these are additional reasons for avoiding concentrating our research exclusively on that part of the organic content of a presumable source rock, fossil or recent, which we obtain by distillation. This matter may not be the real source.

Another rather important question, at which I have already hinted, is whether the shales or limestones we now find associated with oil deposits, and which we accept as being the source material, are already spent rocks or not. I am inclined to believe that many of them may not be exhausted source material. I can not well believe that the oil and gas which we find in such ancient rocks as the Paleozoic, as far back as the Ordovician, have really remained bottled up since those extremely remote times. The material seems too fugitive, too easily migratory, to justify this conception. The majority of the world's oil fields are in the Tertiary, even the late Tertiary. We find many places in the Cretaceous of California, in the early Tertiary of Texas and Louisiana, and elsewhere, where the rocks give evidence of the former existence of oil accumu-

lations, long since dissipated. Gas and oil now occur in beds overlying the Paleozoic oil pools of the Mid-Continent, where they did not originate (upper Red-bed sands) and into which they must have gradually dissipated from the Paleozoic deposits below. This means, in all probability, that more has become entirely lost.

It seems more probable to me that a process is going on, possibly periodic and connected with other cycles of activity in the earth's crust, by which repeated crops of oil and gas are being generated out of the primary source material, to fill the appropriate reservoirs. If this is true, all the organic residue, or at least part of it, that is now left in the presumable source rocks, would not be inconvertible. This would emphasize again the probable intrinsic difference between oil shale and marine shale (and limestone) organic matter.

SUMMARY

The object of these remarks is to emphasize my belief that, if we wish to obtain an answer on the genesis of petroleum, we should cease to concentrate our research exclusively on oil shale, since in all probability this material is not the source rock of our oil deposits.

What the source material really is, is still imperfectly known; we have only theories. The most plausible hypothesis seems to be that it is bituminous marine shale, and in places limestone. We must extend our research through all possibilities, and *include equivalent recent sediments.*

Trask continues to collect bottom samples from numerous favorable regions throughout the world. So much interest in our project has been shown by numerous American and foreign public institutions, leaders of past and present oceanographic expeditions, and individual scientists, that the material at Trask's disposal is rapidly coming to embrace the entire globe, literally from pole to pole. This permits study of the environment required under all climatic and other physical conditions.

The supervising committee of this project No. 4 and Dr. Trask will most gladly coöperate with all other research workers and place at their disposal whatever material they have to spare.

Fossil bituminous marine shales and limestones can easily be collected around all oil fields, notably from well samples, particularly from cores. I am sure that the leading oil companies will coöperate willingly in procuring such material. This recent and fossil material should be studied in addition, or rather in preference, to mere typical oil shales. Investigation should be made not merely of the distillates and extracts of recent and fossil organic sediments but also of the other, larger part of the organic content, not collected in condensers,—particularly the gases driven off at low temperature, before the kerogens decompose.

I realize that this paper is not a very important contribution to the problem of oil genesis, since my remarks are chiefly in the nature of a questionnaire, and do not offer any answers. However, even this analysis of the perplexities which confront us may be useful. I believe that the mode of approach which I have tried to outline is the most desirable and the most likely to lead, possibly, to the answer to these questions which now so greatly vex the petroleum

geologist,—the answer which would be of such enormous practical importance to the prospector.

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT[1]

SCHLOSS HAINFELD
FELDBACH, STEIERMARK, AUSTRIA
May, 1929

STUDY OF THE CROOKED HOLE PROBLEM

For the information of those who may be interested in the study of the crooked hole problem, and in the work of our committee on this study, we may say that the personnel of this committee, as at present composed, includes:

R. P. McLaughlin	Pacific Coast
A. R. Denison	West Texas and southeast New Mexico
W. E. Hubbard	Texas Panhandle
W. C. Thompson	Red River counties and northern Bend Arch counties, Texas
C. H. Row	Laredo district and southwest Texas
F. C. Sealey	Houston district
P. S. Justice	Beaumont district and southern Louisiana
S. P. Borden	Arkansas and northern Louisiana
S. H. Woods	Southern Oklahoma
D. R. Snow	Northern and central Oklahoma
Marvin Lee	Kansas
?	Colorado, Wyoming, and Montana
O. B. Hopkins	Canada; Colombia, South America
T. A. Link	Western Canada
J. French Robinson and J. G. Montgomery, Jr.	Eastern states
E. L. Estabrook	Venezuela
W. P. Haynes	Eastern foreign fields

We are still hoping to add to this list a few from whom we have not yet heard.

These gentlemen are serving as chairmen of local groups, each in his own district. They will be glad to receive data pertaining to the geological aspects of the crooked hole problem or pertaining to the methods of measuring the inclination of holes.

We quote herewith from a letter written by the chairman last June to each of the members of the committee. This is with reference to the questionnaire printed on pp. 854-59 of the July number of this *Bulletin* (1929):

> As I explained in my previous letter to you, this questionnaire was prepared to facilitate our study of the geological aspects of the crooked hole problem. Several of the questions, however, are distinctly related to the mechanical aspects of the problem, which are being investigated by committees of the A. P. I. I included these questions, not in order to duplicate the work of the A. P. I., but to encourage the accumulation of certain important data in the broadest manner possible.

[1]Member of the supervising committee of the American Petroleum Institute Research Project No. 4, "Origin and Environment of Source Sediments."

I want to point out to you, and I wish that you, as a member of our Committee on the Study of the Crooked Hole Problem, would explain clearly to everybody whom you may enlist to aid you in the study, that what we desire now in particular is the accumulation of data and the recording of experiences. Let us gather all the information we can along the lines suggested in the questionnaire. Wherever these data are such as would properly belong in the province of the A. P. I., please pass them on to me and I shall turn them over to Mr. Young of the A. P. I., or turn them over to the A. P. I. representative in your district (sending me a copy). In like manner, I think we should ask the A. P. I. committees on the crooked-hole problem to pass on to us the geological data which they may collect. In other words, for the most efficient results, both organizations should coöperate to the fullest extent, and duplication of writing up or reporting the results should be avoided.

From these data it is my hope to secure subject matter for several instructive and interesting papers on the geological aspects of crooked holes, these papers to be prepared for the 1930 annual meeting of the A. A. P. G. by members of our committee. My idea is that all the data on any specific phase of the problem can be turned over to one man for his careful analysis; and, similarly, all the data on another phase, to another man; and so on. Thus, one of our members might thoroughly discuss the relations of direction of dip of the strata to the direction taken by a hole that goes off the vertical. Another member might gather and describe a number of actual instances where the taking of oriented cores would have saved large sums of money. And so on.

F. H. L.

DALLAS, TEXAS
August 7, 1929

REVIEWS AND NEW PUBLICATIONS

RECENT PUBLICATIONS

BOLIVIA

"Vast Areas of Promising Oil Lands Await Development in the Chaco Plains," by Gilbert P. Moore. *Oil Field Engineering* (Philadelphia, August 1, 1929), pp. 21-23, illus.

BURMA

"The Oilfields of Burma," by L. Dudley Stamp. *Jour. Inst. Petrol. Tech.* (London, June, 1929), Vol. 15, No. 74, pp. 300-49, 18 figs.

COLOMBIA

"Tertic Geology of Colombia," by Antonio M. de Irisarri. *Pan-American Geologist* (Des Moines, Iowa), Vol. 52, No. 1 (August, 1929), pp. 27-38.

COLORADO

"Contribution to the Geology of the Sangre de Cristo Mountains of Colorado," by J. Harlan Johnson. *Colorado Scientific Society* (Denver, 1929), Vol. 12. 21 pp., 2 figs., 1 map. Bibliography. Price, $0.50.

CROOKED HOLES

"Stratameters, Instruments for Securing Geologic Data in Boreholes," by Th. Reinhold. *International Geological Congress, 14th Session*, Madrid, 1926 (1928), pp. 1849-52, 2 figs.

GENERAL

"Drilling for Oil with the Diamond Drill," by G. Heseldin. *Jour. Inst. Petrol. Tech.* (London, June, 1929), Vol. 15, No. 74, pp. 249-99, 14 figs.

"A Comparison of the Conditions of Occurrence of Bituminous Coal and Petroleum," by E. McKenzie Taylor. *Jour. Inst. Petrol. Tech.* (London, June, 1929), Vol. 15, No. 74, pp. 372-84, 1 fig.

"Problems of the Soft-Water Supply of the Dakota Sandstone, with Special Reference to the Conditions at Canton, South Dakota," by O. E. Meinzer. *U. S. Geol. Survey Water-Supply Paper 597-C* (1929). Pp. 147-70, Pl. 20, Figs. 15-18. Free.

"List of Publications of the Department of Commerce" (May 15, 1929, Edition). *Division of Publications, Department of Commerce* (Washington, D. C.). Contains list of publications of the Coast and Geodetic Survey. Free.

"The United States Coast and Geodetic Survey—Its Work, Methods, and Organization" (1928 Revised Edition). *U. S. Coast and Geodetic Survey* (Washington, D. C.). Free.

"Guadalupan Reef Theory," by Charles Keyes. *Pan-American Geologist* (Des Moines, Iowa), Vol. 52, No. 1 (August, 1929), pp. 41-60, 3 pls.

Ingenieurgeologie, by K. A. Redlich, K. v. Terzaghi, and R. Kampe. (Julius Springer, Berlin, 1929) x+708 pp., 417 illus. Price, cloth, RM. 57.

Das Erdöl, seine Physik, Chemie, Geologie, Technologie und sein Wirtschaftsbetrieb, by C. Engler and H. Höfer. In five volumes. Second edition, edited by J. Tausz. Vol. 3, part 2: *Lagerung und Transport des Erdöls und seiner Produkte zu Lande*, by Julius Swoboda. (Hirzel, Leipzig, 1929), 256 pp., 179 illus., 13 tables. Price, RM. 28.

GEOPHYSICS

"Les methodes geophysiques de prospection," by Georges-Albert Boutry. *La Revue Petrolifère* (Paris), Nos. 325-30 (June 15-July 20, 1929).

"Torsion Balance in Determination of the Figure of the Earth," by D. C. Barton. *Amer. Jour. Sci.* (August, 1929), pp. 149-55.

"Astronomical Methods of Determining the Figure of the Earth," by W. D. Lambert. *Amer. Jour. Sci.* (August, 1929), pp. 155-63.

TEXAS

"Subnormal Temperature Gradients in the Permian Basin of Texas and New Mexico," by W. B. Lang. *Jour. Washington (D. C.) Acad. Sci.*, Vol. 19, No. 11 (June 4, 1929).

"Twenty Tests in Southwest Texas Drilled Below 5,000 Feet," by Richard A. Jones. *Oil Weekly* (Houston, Texas, August 16, 1929), pp. 21-23, 106, 1 map, 1 graph.

TRINIDAD

"Notes on a New Mud Volcano in the Sea off the South Coast of Trinidad," by W. G. Weeks. *Jour. Inst. Petrol. Tech.* (London, June, 1929), pp. 385-90.

UNITED STATES AND CANADA

"Les champs petrolifères des Etats-Unis et du Canada." By Ch. Finaton. *La Revue Petrolifère* (Paris), Nos. 322-24, 329-30 (May 25, June 1, 8, July 13, 20, 1929).

THE ASSOCIATION ROUND TABLE

HONORARY MEMBER

HAROLD B. GOODRICH, 1628 South Cincinnati Avenue, Tulsa, Oklahoma, has been elected an honorary member of the Association by the executive committee, in recognition of long and worthy service and in esteem for his faithfulness in maintaining the high standards of the profession of petroleum geology.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

FOR ACTIVE MEMBERSHIP

Michael Abramovich, Baku, U. S. S. R.
I. Tolmachoff, Roswell H. Johnson, R. E. Somers

Ivan James Fenn, Eastland, Tex.
A. C. Trowbridge, Fred B. Plummer, P. G. Russell

James Morris Forgotson, Albuquerque, N. Mex.
William C. Kneale, C. E. Dobbin, C. L. Dake

Harold Milton Fritts, San Angelo, Tex.
Frank C. Greene, Fred B. Plummer, Fred S. Wright

Will Lee Graham, Okemah, Okla.
F. L. Aurin, B. E. Thompson, H. B. Fuqua

Clyde Ludlow Jackson, Midland, Tex.
B. E. Thompson, H. B. Fuqua, Wesley G. Gish

Clemens Leidhold, Wietze, Hannover, Germany
O. Dreher, F. B. Plummer, Frank C. Greene

Willis Archer Maley, San Antonio, Tex.
Hal P. Bybee, Fred B. Plummer, E. H. Sellards

Peter Mason Martin, Coleman, Tex.
R. A. Conkling, F. B. Plummer, P. G. Russell

Wilbur Clyde Ray, San Angelo, Tex.
A. L. Ackers, F. B. Plummer, Edgar Kraus

William Boyd Rowland, Richardson, Tex.
F. W. DeWolf, Marcus A. Hanna, Paul Weaver

Harold Wayne Thoms, Buenos Aires, Argentina, S. A.
Lewis G. Weeks, M. A. Dresser, M. B. Schmittou

FOR ASSOCIATE MEMBERSHIP

Leslie Bowling, Austin, Tex.
Homer A. Noble, J. Brian Eby, John C. Myers
Robert S. Bre'tenstein, New York, N. Y.
J. O. Bower, J. P. McCulloch, James Terry Duce
Delmar Richard Guinn, Amarillo, Tex.
C. Max Bauer, L. R. Hagy, H. E. Crum
William David Henderson, El Dorado, Kan.
C. R. Thomas, J. S. Barwick, Frank T. Clark
Arthur Joseph Holland, Wichita Falls, Tex.
F. K. Foster, R. S. Powell, Vernon E. Autry
Frederick Schoonmaker Lott, Brooklyn, N. Y.
J. J. Galloway, H. N. Coryell, G. Marshall Kay
Francis Herbert McGowan, Houston, Tex.
A. T. Schwennesen, J. Brian Eby, John C. Myers
Andrew Jackson Montgomery, Cushing, Okla.
R. A. Conkling, F. B. Plummer, P. G. Russell
Cecil L. Morgan, Meridian, Miss.
B. W. Blanpied, Corbin D. Fletcher, Gayle Scott
Lindsay George Morgan, Wichita, Kan.
L. W. Kesler, George H. Norton, Marvin Lee
Frank Geary Parris, Clendenin, W. Va.
E. V. O'Rourke, Leon J. Pepperberg, Edwin M. Spieker
Hewlett Ausborn Russell, Big Spring, Tex.
F. B. Plummer, M. E. Roberts, J. S. Hudnall
William DeWitt Waltman, New York, N. Y.
C. H. Wegemann, Max W. Ball, C. A. Fisher

FOR TRANSFER TO ACTIVE MEMBERSHIP

Grant White Corby, Los Angeles, Calif.
Carl M. Beal, R. M. Barnes, R. N. Ferguson
Merle F. Gunby, Roswell, N. Mexico
Sidney Powers, L. E. Trout, A. V. Jones
Marshall Allen Harrell, Dallas, Tex.
Charles H. Row, A. C. Trowbridge, J. R. Reeves

EXECUTIVE COMMITTEE MEETING AT DALLAS, AUGUST 17, 1929

The executive committee met at the Baker Hotel, Dallas, Texas, August 17, 1929, with all members present, namely, president J. Y. Snyder of Shreveport, Louisiana, past-president R. S. McFarland of Tulsa, Oklahoma, first vice-president Fred H. Kay of New York, N. Y., second vice-president A. R. Denison of Fort Worth, Texas, and third vice-president F. H. Lahee of Dallas, Texas.

Headquarters rent.—It was announced that the Tulsa Chamber of Commerce had continued the grant of free rent for Association headquarters in the Tulsa Building for the coming year.

Preprints.—It was agreed that manuscripts submitted for presentation at the New Orleans meeting, March 20-22, 1930, would be selected for preprinting if available by January 15, 1930. It is necessary that the editorial board have ample time to edit such papers before the meeting.

Constitution.—The president was authorized to appoint a committee to consider amending the constitution.

New Orleans.—The committee is planning for a large attendance at the fifteenth annual meeting, New Orleans, Louisiana, March 20, 21, and 22, 1930. Vice-president Lahee has charge of the technical program, which will probably feature crooked holes, geophysics, and the geology and drilling development of the Mississippi embayment.

Structure volume.—It was announced that the first printing of 1,500 copies of *Structure of Typical American Oil Fields*, Volume 1, was nearly exhausted and a second printing of 1,000 copies had been ordered. Volume II of this symposium, containing new material on additional fields and profusely illustrated, will be 200 or more pages larger than Volume I. It will probably be ready for distribution before January, 1930.

Research.—It was decided to establish the I. C. White Gold Medal as recommended by the A. A. P. G. research committee. This award is described in the report of the research committee, published in the July *Bulletin*, p. 876. The executive committee modified the plan of award by stipulating that the past-president of the executive committee should be chairman of the nominating committee. This medal is to be the highest honor conferred by the Association for distinguished contributions to petroleum geology.

The executive committee also adopted the recommendation of the research committee to raise funds for the advancement of geological research (July *Bulletin*, p. 878) and approved appointment by the president of a finance committee, whose chairman will be appointed to the research committee.

Insignia.—In adopting the recommendation of the research committee to establish the I. C. White Gold Medal, the executive committee found it necessary to adopt official insignia for the Association. Designs for a suitable A.A. P. G. emblem will be welcome.

Audit.—It was decided to have the Association business audited semi-annually, as is now being done.

Honorary member.—H. B. Goodrich, petroleum geologist-engineer of Tulsa, Oklahoma, was elected to honorary membership in the Association.

A. A. P. G. INSIGNIA

The Association has never adopted official insignia. It has its own formal seal for signatures on legal documents, but this seal is a plainly worded stamp which portrays nothing of the special character or activity of the organization. It is very desirable that the A. A P. G. have a characteristic and peculiar emblem; furthermore, it is necessary that the Association officially adopt an emblem, now that the executive committee has approved the establishment of the I. C. White Gold Medal, the design of which calls for the insignia of the Association.

On some occasions and for special purposes the Association has used emblematic decorations of one sort or another. The code of ethics, prepared for framing and sent to all new members, is significantly decorated with a two-color seal bearing the gold outlines of crossed pick and hammer on a pictorial background of an oil field showing a typical derrick in the foreground. This design was used effectively in the form of a medal or fob on the badges at one of the annual meetings. Some one has suggested that the more recent instruments used in the exploration for petroleum might well be shown on an emblem representing progressive and up-to-date petroleum geology. The crossed hammers and the plane table seem to hold an original or first-love appeal for the geologist, although they may have to share space on a petroleum geologist's shield with the outline of a core bit or some geophysical instrument.

The committee announces, therefore, that it wishes to receive designs from which it may select an official emblem for the Association. No specific rules have been laid down. It is preferable that the designs be new, though there is much good in those previously used; simple and clear, though sufficiently comprehensive to depict the essentials; typical and usable; symbolic or realistic. Use black ink on plain white paper. Details should be sufficiently distinct to retain legibility if the design is reduced to a diameter of one inch. The committee hopes that interest in the Association will be sufficient incentive for submitting suitable designs. Address Association headquarters, Box 1852, Tulsa, Oklahoma.

PREPRINTS

Through the coöperation of the associate editors and the district representatives and a great many members of local geological groups, we have been able to obtain a very fair idea of the general consensus of opinion regarding the furnishing of preprints at the annual meetings of the A. A. P. G. Probably between 400 and 500 members expressed their views.

Briefly, the majority indicated that preprints of important papers are desirable. In no case, where sufficient consideration was given to the matter, were preprints recommended of all papers submitted for an annual meeting. A few members suggested preprinting only the more important tables, geologic sections, and maps, so that these could be easily referred to during the delivery of the papers.

For those who are interested, we list below some of the advantages and disadvantages submitted by various members.

Among the advantages were these:

1. Preprinting facilitates and stimulates discussion.
2. Those who can not attend the meeting, can secure copies of the papers for reading and for criticism.
3. Many papers are made available much sooner than they would be if they had to wait for publication in the *Bulletin*.
4. Preprints enable the listeners to understand better in halls where the acoustics are poor.
5. Preprints add to the interest at the meeting.

Among the disadvantages these were mentioned:

1. The cost of preprinting may be too great, especially if the type set up for the preprint can not be used again for the final printing in the *Bulletin*.
2. Preprints encourage some to stay away from the session at which the preprinted papers are delivered.
3. Rustling of the leaves of the preprints disturbs the author in his delivery (!).
4. The author would be at a serious disadvantage in the discussions that follow his speech, since many of the expert critics would be fully prepared!
5. Preprints detract from interest at the meeting.

Some of the suggested disadvantages are amusing. To our friend who proposed No. 4, we would urge that the ambition of the author of a paper for our meetings and for our *Bulletin* should not be to place his critics at a disadvantage, in order that he may vanquish them in argument through his present acquaintance with the facts, but rather to assist and promote discussion with the hope (generally fulfilled) of learning more himself.

With regard to our next meeting at New Orleans, March 20-22, 1930, we shall preprint, in part or in full, those papers which seem to us to justify preprinting, provided no unforseen circumstances prevent, and also *only provided these papers are received by the editor or by the business manager on or before January 15, 1920*. We therefore urge prospective contributors to send their finished manuscripts to us before January 15, next.

F. H. L.

PROGRAM FOR NEW ORLEANS MEETING, MARCH 20-22, 1930

Plans are on foot for the program for our next annual meeting, which will be held at New Orleans, March 20-22, 1930. The following subjects have been suggested for particular attention:

1. Geology of the Mississippi embayment area, including Louisiana, Arkansas, Mississippi, and Alabama.
2. Results of geophysical exploration, with reference to areas tested by drilling.
3. Studies of the relations of crooked holes to geology. (Under the direction of the research committee. See this *Bulletin*, July, 1929, p. 853.)

Under each of these topics there is plenty of opportunity for several excellent papers. We shall be glad to hear at an early date from those who contemplate submitting articles on these or other appropriate subjects. We are open to suggestions. If you wish advice, or have ideas, consult the associate editor in your district, or write to the business manager or the editor.

Authors will please observe that, for preprinting, their papers must be in the hands of the editor or the business manager on or before January 15, 1930.

F. H. L.

Memorial

FRANK PARKES LATIMER

Frank Parkes Latimer died in Oklahoma City, December 4, 1928, from complications following a bad case of influenza. At the time of his death, he was geologist in charge of development operations for the Indian Territory Illuminating Oil Company in the Oklahoma City area.

Frank Latimer was born in Clarksville, Texas, August 13, 1903. He was graduated from Oklahoma University, receiving an A. B. degree in geology in June, 1927. He was a member of the professional fraternity *Sigma Gamma Epsilon;* the honorary fraternity *Kappa Tau;* the society fraternity *Alpha Tau Omega.*

He spent two summers with the Oklahoma University summer parties in the Arbuckle Mountains. The summer of 1926, he was with the Indian Territory Illuminating Oil Company as geological scout in the Seminole district and did valuable work for the company in this area.

Immediately after graduation, he continued his work with the Indian Territory Illuminating Oil Company as district geologist at Chickasha and was moved to Oklahoma City when the importance of that area became evident.

Latimer was a man of exceptionally pleasing personality and was a very hard and conscientious worker. He was one of the most promising young geologists the writer has had the good fortune of knowing. He was intensely interested in his work and seemed to have far more originality and initiative than the average young geologist. His untimely death was a shock to his many friends and took from the geological profession a young man of remarkable ability and great promise.

R. J. RIGGS

BARTLESVILLE, OKLAHOMA

August 1, 1929

RUDOLF R. POLLOK

With the passing of Rudolf R. Pollok in San Francisco on June 30, 1929, the petroleum industry lost a geologist who had been connected with certain of the most interesting and successful independent oil company developments and one of the most extraordinary oil districts in the United States.

Born in New York in 1876, he studied in the schools of that city and attended the College of the City of New York from 1889 to 1891 and the Pennsylvania Military College from 1891 to 1894. He prepared himself for civil engineering.

His entrance into the oil industry dates from 1909, when he and his brother formed the A. J. Pollok Company and made engineering and geological reports on various properties in California. This gradually brought him into a closer

association with production. In 1913 he became interested in the Miocene Oil Company, which acquired a 20-acre tract on the Maricopa Flat of Kern County, California. This company developed one of the most profitable gushers of the district. The handling of this well at that early date with proper interpretation of underground water and oil conditions, proper use of cement, proper flow plugs and pressure gauges, together with the simultaneous operation of other wells on the same property from different upper horizons, resulted in a maximum production from a small Maricopa Flat holding that stands as a monument to Rudolf R. Pollok and his associates.

Although his work was mostly in the fields of the San Joaquin Valley of California, he was manager of development for the Cortez Oil Corporation in Mexico from 1913 to the beginning of 1915.

Through his industry he gathered the finest set of early well records available on the Maricopa Flat. In 1920 and 1921, ten of the principal producing companies operating in that area made available all of their records and retained Mr. Pollok and George S. Young to study and report on the detailed underground structure of this rather complicated district. The result was a piece of work that was highly commended by such organizations as the United States Bureau of Mines and the United States Geological Survey.

From his knowledge of one of the early water wells (Anaconda) drilled in the town of Maricopa in 1908, he always maintained that the underlying "Brown shale" of this district, which most oil men arbitrarily considered barren, would eventually be found productive. Recent developments are clearly proving the soundness of this assertion.

With other geologists and engineers he was always generous with the information he had collected. Unfortunately one iniquitous individual imposed on Mr. Pollok's good will and made off with most of these early records. Although this was a great loss, he uttered no unkind sentiments but showed his magnanimity by not even mentioning the name of the culprit.

Of late years he had made his home in Bakersfield with his wife and small son. From this center he kept in close contact with the many new and important oil developments in and about Kern County from the Poso district on the east around to Devil's Den on the west. His ideas in regard to future developments are being vindicated by the fact that the new "Brown shale" discoveries on the Maricopa Flat are leading out to properties which were acquired by those with whom he was associated and were held during a long period of years.

A member of the American Association of Petroleum Geologists, the American Institute of Mining and Metallurgical Engineers, of the Masonic Order, a Shriner, a modest worker and loyal friend, he has lived, achieved, and been a credit to his family, his friends, and his profession.

WALTER STALDER

SAN FRANCISCO, CALIFORNIA
August 2, 1929

HARRY H. WILSON

Harry H. Wilson died in San Angelo, Texas, July 26, 1929, from injuries sustained from an airplane accident in Fort Stockton, Texas. Harry and Paul

Thompson, an engineer for the Phillips Petroleum Company, had been in the air about ten minutes on a sight-seeing plane when the plane crashed from about 200 feet in the air. Harry received a broken back, Thompson a broken ankle and wrist and the pilot escaped with minor bruises. Harry was rushed to the hospital in San Angelo by another airplane, but lived only 24 hours after the accident.

Harry H. Wilson was born in Dennison, Iowa, December 15, 1902. He attended the University of Nebraska in 1921, where he first became interested in the study of geology. He was also a member of the University band, and a member of the Lambda Chi Alpha fraternity. Later, while he was working in the oil fields, he continued his study of geology through extension courses with the University of Chicago.

Harry was superintendent for the Wyland Syndicate in Natrona County, Wyoming, from 1921 until 1925. From 1925 to 1926 he was geologist for H. C. Cook in Nebraska and South Dakota. Then he joined the Phillips Petroleum Company as scout and geologist in the Panhandle of Texas and was stationed in the Amarillo district. He was transferred to the San Angelo district in the fall of 1928 and was there at the time of his death.

Harry was elected an associate member of the American Association of Petroleum Geologists, October 21, 1927. He was also a member of the Masonic order.

Due to his practical experience gained as a tool dresser and general oil field worker before taking up the study of geology, and his training as a scout and in the land department, he had an exceptionally bright future in the oil business and we, his friends and companions, with deep regret saw his promising career cut short by an untimely end.

Those who knew Harry loved him, and the shock of his sudden death was felt more keenly than wo ds can express. Our deep sympathy is extended to his wife and baby daughter and his parents.

WILLIAM L. CLARK

AMARILLO, TEXAS
August 15, 1925

AT HOME AND ABROAD

The International Petroleum Exposition will be held at the exposition grounds, Tulsa, Oklahoma, October 5-12, 1929. The A. A. P. G. will have a booth as usual. All geologists and geological petroleum engineers are invited to visit the booth and register their names.

The Mid-Continent district of the A. P. I. Division of Development and Production Engineering holds its fall meeting in Tulsa, October 7 and 8, during the sixth International Petroleum Exposition and Congress. J. R. McWilliams is district chairman.

The third annual field conference of the Kansas Geological Society will be held in the Black Hills of South Dakota and Wyoming, the Bad Lands of Dawes and Sioux counties, northwestern Nebraska, the Hartville uplift of Platte, Goshen, and Niobrara counties in southeastern Wyoming, and along the Rocky Mountain Front Range from Douglas, Wyoming, to Denver, Colorado. The conference will convene in Rapid City, South Dakota, September 2, and will end in Denver, Colorado, September 13. Further information will be given by Anthony Folger, Box 1144, Wichita, Kansas.

CHARLES H. ROW has been elected by the active members of the San Antonio district as A. A. P. G. representative on the general business committee of the Association for the years 1930 and 1931. Mr. Row is also president of the San Antonio Section of the A. A. P. G.

JOHN R. REEVES, in charge of the geological department of the Empire Companies at Bartlesville, has moved to 329 West Western Avenue, Muskegon, Michigan, to take charge of his company's operations in that district.

The annual meeting and election of officers of the A. A. P. G. Pacific Section will be held in San Francisco, California, November 21 and 22, preceding the California-Stanford football game. Technical sessions will be held between 9 A. M. and 5 P. M. at the Pacific Gas and Electric Company's auditorium on Market Street. There will be a dinner-dance, Thursday evening, November 21, and reservations have been made for a corner of the Palm Room at the Palace Hotel. FRANK S. HUDSON and RALPH D. REED are arranging the technical program. EARL B. NOBLE is president and E. M. BUTTERWORTH is secretary-treasurer of the Section.

LESTER C. UREN, professor of petroleum engineering at the University of California, is author of an article, "Kettleman Hills is Developing Science of Deep Well Drilling," in the *National Petroleum News* for July 31.

GEORGE S. BUCHANAN, consulting geologist of Tulsa, Oklahoma, is in the employ of the Tulsa Oil Company, Petroleum Building, Tulsa.

GLENN D. ROBERTSON, for the past nine years with the Associated Oil Company as geologist and petroleum engineer, has resigned to conduct geological investigations in California for the Cities Service Petroleum Company, Ltd.

LOUIS C. ROBERTS, JR., of the Southern Crude Oil Purchasing Company, has been transferred from the Fort Worth office to 317 Frost National Bank Building, San Antonio, Texas.

C. E. DOBBIN, assisted by C. E. ERDMANN, is working on the structure of the southern part of the Sweetgrass Arch, Montana.

W. T. THOM, JR., has completed a review of the geology of the Crow Indian Reservation, Montana, and during August was at Muskogee, Oklahoma, engaged in further coöperative work for the Oklahoma and U. S. Geological surveys, on the coal levels between Muskogee and Stigler.

ROLLA W. WALLING, assistant petroleum engineer with the Associated Oil Company at Santa Fé Springs, California, had illustrated articles on "Deep-Zone Possibilities in Santa Fé Springs," in the *National Petroleum News* for July 24, and the *Oil Weekly* for August 2.

PAUL FRANKLIN MORSE, geologist for The Texas Company at Houston, died at Seguin, Texas, July 12, from acute appendicitis.

W. W. MCDONALD is in charge of the district new office of the Arkansas Fuel Company at Wichita Falls, Texas.

H. T. MORLEY, district geologist for the Midwest Refining Company at Abilene, has been transferred to Amarillo, Texas.

ROSWELL H. JOHNSON, of the University of Pittsburgh, spent the summer in Baku doing geological work, making reserve estimations, and lecturing for Azneft, the company controlling the oil fields at Baku, U. S. S. R.

JOHN J. DOYLE, of the land department of the Humble Oil and Refining Company, has moved from Shreveport, Louisiana, to Beaumont, Texas.

E. W. SHAW, chief geologist for the Iraq Petroleum Company, Ltd., may be reached at their London office, King William St. House, Arthur Street, London, E. C. 4.

C. L. BOWEN, of New York City, has returned from a trip to the East Indies.

HENRY G. SCHNEIDER, chief geologist of the Dixie Oil Company, Inc., has moved his office from Shreveport to Tulsa.

H. D. EASTON, consulting geologist of Shreveport, Louisiana, published in *The Mississippi Builder* for July, 1929, a paper entitled "Mississippi, an Oil State."

E. L. DEGOLYER, of New York City, president of the Rycade Oil Corporation, made a business trip to England in September.

JOSEPH H. SINCLAIR, consulting geologist, New York City, spent the summer at Calgary, Alberta, recovering from a long illness and doing some consulting work.

D. B. STERRETT, consulting geologist of Washington, D. C., spent the summer at Calgary, Alberta, on professional work.

BETTY KELLETT has joined the micropaleontological staff of the Amerada Petroleum Corporation at Tulsa.

DOUGLAS R. SEMMES, consulting geologist, has headquarters at 1901 W. T. Waggoner Building, Fort Worth, Texas.

W. Z. MILLER, consulting geologist of Tulsa, Oklahoma, spent the summer on professional work in the Rocky Mountain area.

R. P. MCLAUGHLIN, of Los Angeles, California, has invented a clinograph for measuring the deflection of wells. It is described in the *Oil Bulletin*, Los Angeles, August, 1929.

FRED B. ELY, consulting geologist, has moved his office to 11 Broadway, New York City.

C. H. WEGEMANN has his office at 122 East 42d Street, New York City.

RALPH ARNOLD, 1201 East California Street, Pasadena, California, is writing a book, *Data of the Petroleum Industry*.

J. J. MAUCINI, district geologist for the Continental Oil Company, has been transferred back to Amarillo.

GLENN C. CLARK, of Ponca City, Oklahoma, is chief geologist of the Continental Oil Company.

T. G. MADGWICK, of the Department of the Interior, Ottawa, Canada, has visited the California and Mid-Continent oil fields, studying gas conservation.

FRANK REEVES, of the U. S. Geological Survey, spent the summer on leave of absence in the employ of the Imperial Oil Company of Canada.

D. D. HUGHES is in charge of the micropaleontological work of The Texas Company of California at Los Angeles, California.

GEORGE H. DOANE is head of the micropaleontological department of the Pacific Western Oil Company at Los Angeles, California.

RALPH D. REED is in charge of the exploration department of The Texas Company of California. He was formerly connected with the Marland Oil Company.

C. O. NICKELL, formerly with the Continental Oil Company, is now engaged in consulting practice at Wichita Falls, Texas.

E. R. AMES, formerly of Houston, Texas, has recently joined the Texas Creosoting Company, Orange, Texas. He is at present engaged in forming a new department to serve the petroleum industry as regards the use of creosoted timber in various construction works.

CHESTER W. WASHBURNE, assisted by JOVIANO PACHECO and DOMICIO PACHECO e SILVA, has completed a study of the geology and oil prospects of the state of São Paulo, Brazil. After some excursions into other states of Brazil and to the Argentine Republic, he will do some work in Europe. He may be reached through his office, 27 William Street, New York City. His family, with one new addition, a girl, are at Villa des Charmilles, Menthon, St. Bernard (Lac d'Annecy), Haute Savoie, France.

CHARLES N. GOULD, director of the Oklahoma Geological Survey, Norman, Oklahoma, has an article entitled "Scientist Doesn't Pretend to Find Oil" in the August 22 issue of *Oil and Gas Journal*.

DON DANVERS is in charge of the Sinclair Oil and Gas Company office in San Antonio, Texas.

P. W. MCFARLAND, geologist with the Sun Oil Company, at the San Antonio office, has been transferred to the head office at Dallas, Texas.

D. EYOUB, geologist with the Empire Gas and Fuel Company in southwest Texas and Mexico, has gone to Colombia, South America, where he will do several months' work for the company.

RALPH ARNOLD, geologist and producer, Los Angeles, California, has been elected a Fellow of the California Academy of Sciences.

CHARLES H. PISHNY, production engineer with the Amerada Petroleum Corporation at Tulsa, Oklahoma, is the author of an article on "Artificial Methods of Oil Recovery" in the *Oil and Gas Journal* of August 22.

J. J. GALLOWAY of Columbia University, New York City, spent the summer in the Mid-Continent region for the Gypsy Oil Company, making a special study of micropaleontology.

C. R. THOMAS, El Dorado, Kansas, who has had charge of the geological work in Kansas for the Skelly Oil Company for the last two years, has resigned this position in order to undertake independent operations.

RAYMOND H. GOODRICH has resigned from the Humble Oil and Refining Company to engage in consulting work in Houston.

J. D. THOMPSON, JR., who has had charge of the geological subsurface work in the Texas Panhandle and West Texas territories during the past seven and one-half years, for the Gulf Production Company, is opening a consulting office in Amarillo, Texas. He will specialize on the Texas Panhandle and adjoining territories.

PROFESSIONAL DIRECTORY

SPACE FOR PROFESSIONAL CARDS IS RESERVED FOR ACTIVE MEMBERS OF THE ASSOCIATION. FOR RATES, APPLY TO THE BUSINESS MANAGER, BOX 1852, TULSA, OKLAHOMA

CHESTER W. WASHBURNE
GEOLOGIST
27 WILLIAMS ST. NEW YORK

HUNTLEY & HUNTLEY
PETROLEUM GEOLOGISTS AND ENGINEERS
L. G. HUNTLEY
SHIRLEY L. MASON
J. R. WYLIE, JR.
GRANT BUILDING, PITTSBURGH, PA.

EDWIN B. HOPKINS
CONSULTING GEOLOGIST
25 BROADWAY NEW YORK CITY

GEO. C. MATSON
GEOLOGIST
614 TULSA TRUST BUILDING TULSA, OKLA.

JAMES L. DARNELL
ENGINEER
420 LEXINGTON AVE. NEW YORK CITY

DABNEY E. PETTY
CHIEF GEOLOGIST
PETTY GEOPHYSICAL ENGINEERING COMPANY
SAN ANTONIO, TEXAS

RALPH E. DAVIS
ENGINEER
GEOLOGICAL EXAMINATIONS
APPRAISALS
1710 UNION BANK BLDG. PITTSBURGH, PENN.

DEWITT T. RING
GEOLOGIST
99 NORTH FRONT ST. COLUMBUS, OHIO

FRANK W. DEWOLF
THE LOUISIANA LAND & EXPLORATION CO.
ESPERSON BUILDING HOUSTON, TEX.

FRANK A. HERALD
GEOLOGIST AND PETROLEUM ENGINEER
1805 ELECTRIC BUILDING
FORT WORTH, TEXAS

E. DeGOLYER

GEOLOGIST

65 BROADWAY NEW YORK

M. M. VALERIUS

PETROLEUM GEOLOGIST

101-102 WILCOX BLDG.

TULSA OKLAHOMA

PHILLIP MAVERICK

PETROLEUM GEOLOGIST

RUST BUILDING

SAN ANGELO TEXAS

JOHN L. RICH

GEOLOGIST

OTTAWA KANSAS

STUART ST. CLAIR

CONSULTING GEOLOGIST

HUDSON VIEW GARDENS NEW YORK CITY

BROKAW, DIXON, GARNER & McKEE

GEOLOGISTS PETROLEUM ENGINEERS
EXAMINATIONS APPRAISALS
ESTIMATES OF OIL RESERVES

120 BROADWAY NEW YORK CARACAS VENEZUELA

JOSEPH A. TAFF

CONSULTING GEOLOGIST
ASSOCIATED OIL CO.
79 NEW MONTGOMERY ST.

SOUTHERN PACIFIC COMPANY
65 MARKET ST.

SAN FRANCISCO

W. E. WRATHER

PETROLEUM GEOLOGIST

4300 OVERHILL DRIVE

DALLAS TEXAS

R. W. LAUGHLIN L. D. SIMMONS

WELL ELEVATIONS
OKLAHOMA AND KANSAS

LAUGHLIN-SIMMONS & CO.

605 OKLAHOMA GAS BUILDING

TULSA OKLAHOMA

FREDERICK W. GARNJOST

SPUYTEN DUYVIL
NEW YORK CITY

ALEXANDER DEUSSEN

CONSULTING GEOLOGIST

SPECIALIST, GULF COAST SALT DOMES

1606 POST DISPATCH BUILDING
HOUSTON, TEXAS

FREDERICK G. CLAPP

50 CHURCH STREET

NEW YORK

IRVINE E. STEWART

1010 TEXAS COMPANY BUILDING

LOS ANGELES, CALIFORNIA

JOHN M. HERALD

GEOLOGIST AND
PETROLEUM ENGINEER

303 COSDEN BUILDING TULSA, OKLAHOMA

LOWELL J. RIDINGS

GEOLOGIST

EXAMINATIONS - APPRAISALS - FIELD PARTIES

MEXICO AND SOUTH AMERICA

APARTADO 344 TAMPICO

WALTER STALDER

PETROLEUM GEOLOGIST

925 CROCKER BUILDING

SAN FRANSCISCO, CALIFORNIA

L. A. MYLIUS

PETROLEUM ENGINEER

1711 EXCHANGE NATL.
BANK BLDG. TULSA, OKLAHOMA

WALLACE E. PRATT

918 HUMBLE BUILDING
HOUSTON, TEXAS

FRED H. KAY

PAN-AMERICAN PETROLEUM AND TRANSPORT COMPANY

122 E. 42ND STREET NEW YORK

PHIL B. DOLMAN

GEOLOGIST

MINING AND PETROLEUM

SAN FRANCISCO

FRANK BUTTRAM

PRESIDENT

BUTTRAM PETROLEUM CORPORATION

NOT OPEN FOR CONSULTING WORK

313-314 MERCANTILE BLDG.

PHONE MAPLE 7277

OKLAHOMA CITY, OKLA.

JOHN B. KERR

PETROLEUM GEOLOGIST

508 BALBOA BUILDING

SAN FRANCISCO CALIFORNIA

CHARLES T. LUPTON

CONSULTING
GEOLOGIST

FIRST NATIONAL BANK BLDG.
DENVER, COLORADO

J. E. EATON

CONSULTING GEOLOGIST

FOREIGN AND DOMESTIC FIELD PARTIES

628 PETROLEUM SECURITIES BLDG.
LOS ANGELES CALIFORNIA

J. P. SCHUMACHER
R. Y. PAGAN
W. G. SAVILLE
A. C. PAGAN

TORSION BALANCE EXPLORATION CO.

TORSION BALANCE SURVEYS

PHONE: PRESTON 7315
730-32 POST DISPATCH BUILDING

HOUSTON TEXAS

WILLIS STORM

4501 LIVINGSTON

PETRO ROYALTY CORP. DALLAS, TEXAS

G. JEFFREYS

CONSULTING GEOLOGIST

PHONE JOHN 2584

80 MAIDEN LANE NEW YORK

PAUL P. GOUDKOFF

GEOLOGIST

GEOLOGIC CORRELATION BY FORAMINIFERA AND MINERAL GRAINS

1222-24 SUBWAY TERMINAL BUILDING
LOS ANGELES, CALIFORNIA

HARRY W. OBORNE

GEOLOGIST

420 EAST SAN RAFAEL ST.
COLORADO SPRINGS
PHONE MAIN 1189

309 EAST OLIVE ST.
LAMAR, COLO.
PHONE 303

C. DON HUGHES

PETROLEUM GEOLOGIST

OLIVER-EAKLE BLDG.

AMARILLO, TEXAS

F. B. PORTER
PRESIDENT
R. H. FASH
VICE-PRESIDENT

THE FORT WORTH LABORATORIES

ANALYSES OF BRINES, GAS, MINERALS, OIL. INTERPRETATION OF WATER ANALYSES. FIELD GAS TESTING.

828½ MONROE STREET FORT WORTH, TEXAS
LONG DISTANCE 138

DONALD C. BARTON

CONSULTING GEOLOGIST AND GEOPHYSICIST

SPECIALIST ON EOTVOS TORSION BALANCE

717 PETROLEUM BUILDING

HOUSTON TEXAS

FRED B. ELY

CONSULTING GEOLOGIST

11 BROADWAY NEW YORK CITY

GEORGE S. BUCHANAN

GEOLOGIST

1102 ATLAS LIFE BUILDING

TULSA OKLAHOMA

J. S. HUDNALL
G. W. PIRTLE

HUDNALL & PIRTLE

GEOLOGISTS

COLEMAN TEXAS

CARROLL H. WEGEMANN

CHIEF GEOLOGIST

PAN AMERICAN PETROLEUM & TRANSPORT CO.

120 BROADWAY

NEW YORK

BASIL B. ZAVOICO
CONSULTING GEOLOGIST AND PETROLEUM ENGINEER
501 PHILTOWER BUILDING
TULSA, OKLA.

NEW YORK OFFICE
11 BROADWAY
PHONE: 4208 BOWLING GREEN

C. MAX BAUER
CONSULTING GEOLOGIST
THE MIDWEST REFINING COMPANY
ROUTE 3, BOX 116, BOULDER, COLORADO

OPEN FOR LIMITED ENGAGEMENTS

DIRECTORY OF GEOLOGICAL SOCIETIES

FOR THE INFORMATION OF GEOLOGISTS VISITING LOCAL GROUPS. FOR SPACE, APPLY TO THE BUSINESS MANAGER, BOX 1852, TULSA, OKLAHOMA

PANHANDLE GEOLOGICAL SOCIETY

AMARILLO, TEXAS

PRESIDENT - - - - - - H. E. CRUM
SKELLY OIL COMPANY

VICE-PRESIDENT - - - - W. E. HUBBARD
HUMBLE OIL & REFINING COMPANY

VICE-PRESIDENT - - - VICTOR COTNER
P NEY OIL COMPANY

SECRETARY-TREASURER - DELMAR R. GUINN
EMPIRE GAS & FUEL COMPANY

MEETINGS: FIRST AND THIRD FRIDAY NOONS EACH MONTH. PLACE: LONG HORN ROOM, AMARILLO HOTEL

NORTH TEXAS GEOLOGICAL SOCIETY

WICHITA FALLS, TEXAS

PRESIDENT - - - - WARD C. BEAN
SHELL PETROLEUM CORPORATION

VICE-PRESIDENT - - - J. B. LOVEJOY
GULF PRODUCTION COMPANY

SECRETARY-TREASURER - F. K. FOSTER
SINCLAIR OIL & GAS COMPANY

MEETINGS: SECOND AND FOURTH SATURDAYS EACH MONTH, AT 6:30 P. M.
PLACE: WICHITA CLUB, CITY NATIONAL BANK BLDG.

TULSA GEOLOGICAL SOCIETY

TULSA, OKLAHOMA

PRESIDENT - - - - - - A. I. LEVORSEN
INDEPENDENT OIL & GAS COMPANY

1ST VICE-PRESIDENT - - H. E. ROTHROCK
SUPERIOR OIL CORPORATION

2ND VICE-PRESIDENT - - HARRY H. NOWLAN
DARBY PETROLEUM CORPORAT ON

SECRETARY-TREASURER - WILLIAM W. KEELER
MINNEHOMA OIL & GAS COMPANY

MEETINGS: FIRST AND THIRD MONDAYS EACH MONTH, FROM OCTOBER TO MAY, INCLUSIVE, AT 8:00 P. M., FOURTH FLOOR, TULSA BUILDING. LUNCHEONS: EVERY THURSDAY, FOURTH FLOOR, TULSA BUILDING.

KANSAS GEOLOGICAL SOCIETY

WICHITA, KANSAS

PRESIDENT - - - - JOHN R. REEVES
EMPIRE OIL & REFINING CO.
OIL HILL, KANSAS

VICE-PRESIDENT - RICHARD B. RUTLEDGE
BARNSDALL OIL COMPANY

SECRETARY-TREASURER - ANTHONY FOLGER
GYPSY OIL COMPANY

REGULAR MEETINGS 12:30 P. M., AT INNES TEA ROOM, THE FIRST SATURDAY OF EACH MONTH. VISITING GEOLOGISTS ARE WELCOME.

THE KANSAS GEOLOGICAL SOCIETY SPONSORS THE WELL LOG BUREAU WHICH IS LOCATED AT 719-20 UNION NATIONAL BANK BUILDING.

THE SHREVEPORT GEOLOGICAL SOCIETY

SHREVEPORT, LOUISIANA

PRESIDENT - - - - - S. P. BORDEN
CONSULTING GEOLOGIST,
ROOM 621, ARDIS BLDG.

VICE-PRESIDENT - - - GEORGE BELCHIC
BELCHIC & LASKEY
SLATTERY BLDG.

SECRETARY-TREASURER - - W. F. CHISHOLM
MINERALS DIVISION,
DEPT. CONSERVATION, WARD BLDG.

MEETS THE FIRST FRIDAY OF EVERY MONTH, ROOM 605, SLATTERY BUILDING. LUNCHEON EVERY MONDAY NOON, WASHINGTON HOTEL.

HOUSTON GEOLOGICAL SOCIETY

HOUSTON, TEXAS

PRESIDENT - - - - - - PAUL WEAVER
GULF PRODUCTION COMPANY

VICE-PRESIDENT - - - - JOHN M. VETTER
SECOND NATIONAL BANK BUILDING

SECRETARY-TREASURER - - MARCUS A. HANNA
GULF PRODUCTION COMPANY

REGULAR MEETINGS EVERY TUESDAY AT NOON AT THE RICE HOTEL. FREQUENT SPECIAL MEETINGS CALLED BY THE EXECUTIVE COMMITTEE. FOR ANY PARTICULARS PERTAINING TO MEETINGS CALL THE SECRETARY.

DALLAS PETROLEUM GEOLOGISTS

DALLAS, TEXAS

CHAIRMAN - - - - - - F. E. HEATH
SUN OIL CO.

VICE-CHAIRMAN - - - - H. B. HILL
U. S. BUREAU OF MINES

SECRETARY-TREASURER - KARL H. SCHILLING
SHELL PETROLEUM CORP.

MEETINGS: ALTERNATE MONDAYS, 6:00 P. M., USUALLY AT BAKER HOTEL. VISITING GEOLOGISTS ALWAYS WELCOME AND URGED TO ATTEND. ADDITIONAL INFORMATION ON MEETINGS BY CALLING SECRETARY.

WEST TEXAS GEOLOGICAL SOCIETY

SAN ANGELO, TEXAS

PRESIDENT - - - - V. E. COTTINGHAM
COTTINGHAM AND BRISCOE

VICE-PRESIDENT - - - - A. L. ACKERS
SOUTHERN CRUDE OIL PURCHASING CO., MIDLAND

SECRETARY-TREASURER - - - G. E. GREEN
VACUUM OIL COMPANY, MIDLAND

MEETINGS: FIRST SATURDAY EACH MONTH AT 7:30 P. M., ST. ANGELUS HOTEL. LUNCHEON: THIRD SATURDAY EACH MONTH AT 12:15.

SHAWNEE GEOLOGICAL SOCIETY

SHAWNEE, OKLAHOMA

PRESIDENT - - - - - - JESS VERNON
AMERADA PETROLEUM CORPORATION

VICE-PRESIDENT - - - OSCAR HATCHER
GYPSY OIL COMPANY

SECRETARY-TREASURER - - - H. H. KISTER
DIXIE OIL COMPANY, INC.

MEETS THE FOURTH MONDAY NIGHT OF EACH MONTH AT 7:00 P. M., MAIN DINING ROOM OF HILTON PHILLIPS HOTEL. VISITING GEOLOGISTS ARE WELCOME AT THE MEETINGS.

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS

PRESIDENT - - - - JOSEPH S. IRWIN
CONSULTING GEOLOGIST
935 ST. PAUL STREET

VICE-PRESIDENT - - CHAS. S. LAVINGTON
CONTINENTAL OIL COMPANY

VICE-PRESIDENT - - J. HARLAN JOHNSON
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO

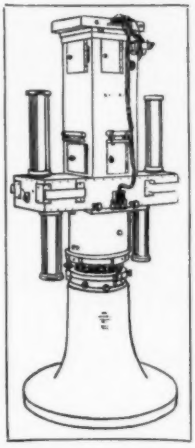
SECRETARY-TREASURER - W. A. WALDSCHMIDT
MIDWEST REFINING COMPANY

LUNCHEON MEETINGS FIRST AND THIRD THURSDAYS OF EACH MONTH; 12:15 P. M. AUDITORIUM HOTEL.

Geophysical Instruments for the Exploration of Mineral Deposits

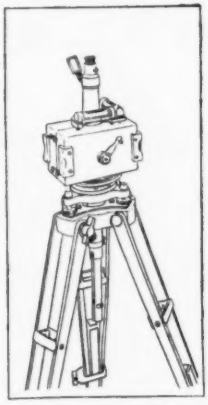
Their application cannot be separated from

The Future of the American Oil Industry



Small Torsion Balance, Schweydar Model

More than ever before the petroleum geologist depends on quick and reliable information about the subsurface conditions, especially in unexplored areas with little or no surface indications. It is the merit of our torsion balances and magnetometers that they have greatly assisted geologists of many leading American operating companies in their exploration work. They have proved through the test of time the accuracy of their analysis.



Vertical Magnetometer, Improved Model

FOR ECONOMICAL EXPLORATION USE OUR GEOPHYSICAL INSTRUMENTS

We are making and selling for geophysical work: Torsion balances, large and small models with automatic recording and visual reading; magnetometers; earth inductors; seismographs, Schweydar model.

We train your personnel without charge

Write for bulletins

AMERICAN ASKANIA CORPORATION

1024 MARINE BANK BUILDING - - - HOUSTON, TEXAS

Original Eötvös Torsion Balances

(Visual Observation)

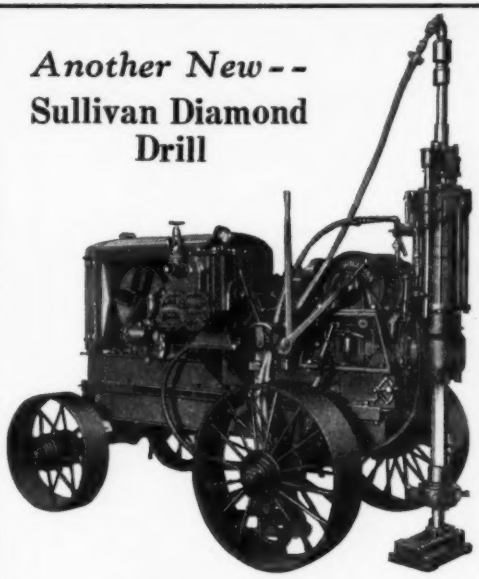
Rybar Torsion Balances

(Automatic and Visual)

Sold, or surveys executed.

Sole Representative for
NORTH-CENTRAL-SOUTH AMERICA
GEORGE STEINER
Petroleum Bldg.
Houston, Tex.

Another New--
Sullivan Diamond Drill



Sullivan "40"

Sullivan "40" replaces the famous "CN" structure drill, which has many records to its credit. The first "CN" has made more than 135,000 feet of hole. Another, recently, in one month, moved sixteen times from one to three miles, and drilled 6,900 feet of hole.

Yet, successful as the "CN" was, Sullivan "40" is superior to it in many ways. It drills a 3-inch hole (2-inch core) to 1,200 feet; or a 2-inch hole (1⅜-inch core) to 2,200 feet. It is shorter and weighs only 8,300 lbs.

The hydraulic swivel head has a feed of 18 inches. The drill can be run back off the hole 18 inches, on its tracks. It is readily adapted for use with a Kelly for rapid fish-tail work. The hoist picks up, holds, or lowers a load of 3,000 lbs. at a touch of the fingers.

The engine is 50% more powerful than that used on the older "CN".

Four drilling and four hoisting speeds are available. The wagon mounting is sturdy, and close coupled so it can be turned around in cramped quarters.

A complete description is in a new **Catalog No. 85-F.**

SULLIVAN MACHINERY COMPANY
412 N. Michigan Avenue
CHICAGO
New York St. Louis Garber Dallas Denver
San Francisco Spokane London

CARBON
Black Diamonds
- for -
Diamond Core Drills

Quality - Service

THE DIAMOND DRILL CARBON CO.
63 Park Row
New York City
Cable Address: CREDOTAN, N. Y.

We Look into the Earth

by using the Diamond Core Drill and bringing out a core of all strata so that it can be examined and tested.

Shallow holes to determine structure can be drilled at low cost.

Core drill can be used to complete test that has failed to reach desired depth. In many places "wild cat" wells can be drilled with the core drill at a fraction of the cost for large hole and the core shows nature and thickness of oil sands.

PENNSYLVANIA DRILLING CO.
Pittsburgh, Pa.
CORE DRILLING CONTRACTORS
Cable Andress PENNDRILL, Pittsburgh

JOURNAL OF PALEONTOLOGY

A publication devoted to scientific papers on paleontology and sedimentary petrography with special reference to new researches in micro-paleontology and descriptions of fossils important for the correlation and identification of oil-field formations.

Published four times a year by the Society of Economic Paleontologists and Mineralogists, affiliated with the American Association of Petroleum Geologists.

J. A. CUSHMAN, *Editor*
76 Brook Road, Sharon, Mass.

Volumes I and II now issued, Volume III in press. Volume I contains more than fifty plates of fossils, numerous text figures, and diagrams accompanying papers by Cushman, Galloway, Hanna (M. A. and G. D.), Gardner, Berry, Vaughan, Scott, Roundy, Alexander, Waters, Thomas, Cox, van der Vlerk, Harlton, Driver, Church, and Stadnichenko.

Volume II contains 59 plates and numerous figures accompanying articles by Alexander, Howe, White, Hanna, Vaughan, Cushman, Galloway, Coryell, Nuttall, Knight, R. C. Moore, and others.

The Journal of Paleontology is a helpful handbook to the student of paleontology and a necessary addition to every scientific library.

Subscription price is $6.00 per year ($2.00 for single numbers).

Address communications regarding subscriptions to F. B. Plummer, secretary-treasurer, Bureau of Economic Geology, Austin, Texas.

Back numbers, as far as they are in stock, for sale by J. P. D. Hull, business manager A. A. P. G., Box 1852, Tulsa, Oklahoma.

ANNOTATED BIBLIOGRAPHY OF ECONOMIC GEOLOGY

Sponsored by the
NATIONAL RESEARCH COUNCIL

Will cover articles on all metallic and non-metallic deposits (including petroleum and gas), hydrology, engineering geology, soils (insofar as related to geology), and all subjects that have any bearing on economic geology.

The collection of the titles and the preparation of the abstracts will be under the direction of Mr. J. M. Nickles.

The bibliography covering 1928 will appear in a single volume of about 400 pages which, it is expected, will be ready for distribution about June 1, 1929. In succeeding years, however, two volumes of about 200 pages each will be published at intervals of about six months.

In order to gain some idea of the number of copies necessary to supply the demand, advance subscriptions are now being solicited.

The price of the Bibliography will not exceed $5.00 per year.

Kindly send orders to the undersigned at your early convenience.

ECONOMIC GEOLOGY,
Urbana, Illinois, U. S. A.

"The most useful A. A. P. G. publication outside the *Bulletin*"

Volume I of the symposium on the relation of oil accumulation to structure

Structure of Typical American Oil Fields

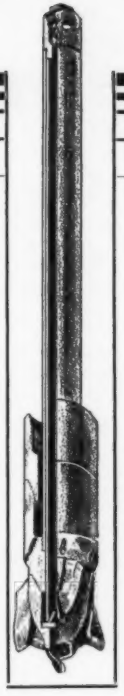
Thirty papers describing typical fields in Arkansas, California, Indiana, Kansas, Kentucky, Louisiana, Michigan, New Mexico. Ohio, Oklahoma, Tennessee, Texas, and West Virginia, especially contributed by thirty-nine authors familiar with their respective fields.

510 pp., 194 illus. 6x9 inches. Blue cloth. Gilt title.

NOW READY. PRICE, $5.00, POSTPAID
($4.00 TO MEMBERS)

American Association of Petroleum Geologists

Box 1852 **Tulsa, Oklahoma**



The **Perfection**

Core Barrel

—will take a *20-foot core* when you want it. The "split liner" permits the removal of each core—quickly and *unbroken*.

—in use by more than 80% of the major oil companies in the mid-continent field, and hundreds of others elsewhere.

The
Brewster
A. P. I.
Shouldered
Tool Joints

will not "back off" going into the hole.

The Brewster COMPANY~INC.
SUCCESSORS TO OIL CITY IRON WORKS, INC.
Shreveport, Louisiana

Write or wire today for catalog and prices . . . . no obligation

Leitz Petrological Microscope "CM"

LEITZ

Petrological (Polarising) Microscopes

are the Standard for

OIL GEOLOGISTS

in their petrological investigations

The Oil Geologists have come to the realization that only the most precise equipment will render dependable and unfailing results. ***The Leitz Petrological Microscopes meet the most exacting requirements for routine and research work, due to Superior Workmanship and Perfect Alignment.***

Leading Institutions, Government Departments and Industrial Laboratories throughout the world recognize these indisputable features and have adopted Leitz Petrological Microscopes as Standard for their Investigations.

Write for Catalog No. III-*B* (*V*)

E. LEITZ, Inc.

60 EAST 10th ST. NEW YORK

AGENTS:

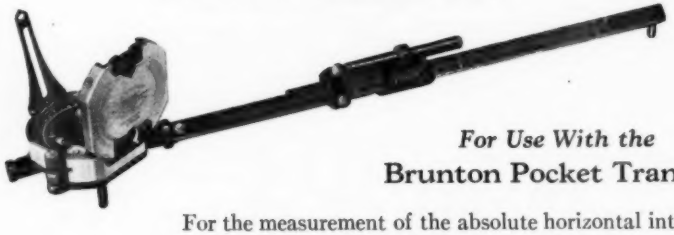
Pacific Coast States: Spindler & Sauppé, Offices at San Francisco and Los Angeles, California

Washington District: E. Leitz, Inc., Investment Bldg., Washington, D. C.

Chicago District: E. Leitz, Inc., 122 So. Michigan Ave., Chicago, Ill.

Canada: The J. F. Hartz Co., Ltd., Toronto 2, Canada

The Wilson Magnetometer Attachment



For Use With the

Brunton Pocket Transit

For the measurement of the absolute horizontal intensity of the earth's magnetic field with a degree of accuracy comparable with its size and portability.

Ask for BULLETIN C-5

Prompt attention given to the repair and adjustment of Torsion balances, magnetometers, scientific and surveying instruments.

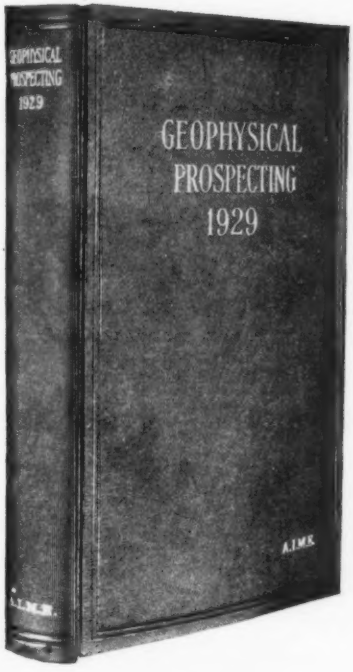
WM. AINSWORTH & SONS, INC.

THE PRECISION FACTORY

2151 Lawrence Street Denver, Colorado, U. S. A.

Mining and Oil Men, Geologists, Physicists

Are You Aware



that the first collection of papers presented by the A. I. M. E. Committee on Geophysical Prospecting is now available?

The papers in this special volume were presented at the New York, 1928, and Boston, 1928, meetings. A few address the specialist; others afford mining men an insight into the economic value of particular methods. Two are general in application; nine treat of electrical, seven of magnetic, six of gravity, and three of seismic methods.

A copy of this book has been mailed to all members of the A. I. M. E. who have requested the Geophysical Prospecting papers. Other members may have a copy on request without charge.

27 Papers
676 Pages
6 x 9 Inches
25 Authors
Illustrated
Price $5.00

American Institute of Mining & Metallurgical Engineers, Inc.
29 West 39th St., New York, N. Y.

Please send me.....copies of the volume, "Geophysical Prospecting, 1929," for which I enclose $.....

Name.....

Address.....

Authors contributing to this book are:

Max Mason	Warren Weaver
Allen H. Rogers	Hans Lundberg
W. O. Hotchkiss	Karl Sundberg
W. J. Rooney	Allan Nordstrom
James Fisher	J. J. Jakosky
E. G. Leonardon	L. B. Slichter
Sherwin F. Kelly	C. A. Heiland
Irving B. Crosby	Noel H. Stern
G. Carrette	W. H. Courtier
J. G. Koenigsberger	H. R. Aldrich
Frank Rieber	Donald C. Barton
E. Lancaster-Jones	H. Shaw
P. W. George	

Sample Envelopes and Sub-Surface Data Sheets

are included in our stock of Standardized Oil Accounting and Field Forms

INVESTIGATE the CONVENIENCE of USING THEM

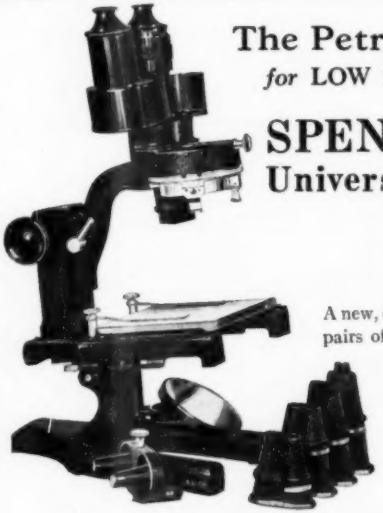
In our price list we also show more than 200 other printed forms for your office and field use.

The MID-WEST PRINTING CO.

Phone 3-3176
P. O. Box 1465
317 S. Detroit
Tulsa, Okla.

Standardized Oil Accounting and Field Forms

Catalogs
Booklets
Office Forms
Stationery



The Petroleum Geologist's IDEAL *for* LOW POWER, LARGE AND WIDE FIELD

SPENCER NEW MODELS

Universal Binocular Microscopes

Nos. 55 and 56 equipped with

Multiple Nosepiece

A new, original, patented objective changer which carries three pairs of low power objectives and revolves like an ordinary nosepiece. The objectives may be removed instantly and others substituted.

The objectives on the nosepiece are dust proof and the worker can easily get to them to clean them.

NEW—ORIGINAL—BETTER

New Catalog M-35 features it

SPENCER BUFFALO USA

SPENCER LENS COMPANY

Manufacturers

Microscopes, Microtomes, Delineascopes, Optical Measuring Instruments, Dissecting Instruments, etc.

BUFFALO, N. Y.

SPENCER BUFFALO USA

Branches: New York Boston Chicago San Francisco Washington

REVUE DE GÉOLOGIE
ET DES SCIENCES CONNEXES

Monthly review of geology and connected sciences under the auspices of

SOCIÉTÉ GÉOLOGIQUE DE BELGIQUE
with the collaboration of

The American Mineralogist, Société Géologique de France, Service Géologique de Pologne, Comitato della Rassegna di Geologia, Several Official Geological Surveys, Australian Science Abstracts, Bureau d'Histoire Naturelle de Prague, and numerous Geologists of all parts of the World.

GENERAL OFFICE of the "*Revue de Géologie*"
Institut de Géologie, Université de Liége, Belgique

TREASURER of the "*Revue de Géologie*"
35, Rue des Armuriers, Liége, Belgique

PRICES: Vol. I (1920) $10.00, Vol. II (1921) $8.00 Vol. III (1922) $7.50, Vol. IV (1923) $7.00, Vol. V (1924) $6.50, Vol. VI (1925) $6.00, Vol. VII (1926) $5.50, Vol. VIII (1927) $5.50, Vol. IX (1928) $5.00, Vol. X (1929) $5.00 (subscription price). Moderate extra rate for cover if wanted.

SAMPLE COPY SENT ON REQUEST

Announcing

THE GEOLOGY OF VENEZUELA AND TRINIDAD

By

Ralph Alexander Liddle

A Systematic Treatise on

the physiography, stratigraphy, general structure, and economic geology of the United States of Venezuela and the British Island of Trinidad. The first comprehensive work on the geology of Venezuela.

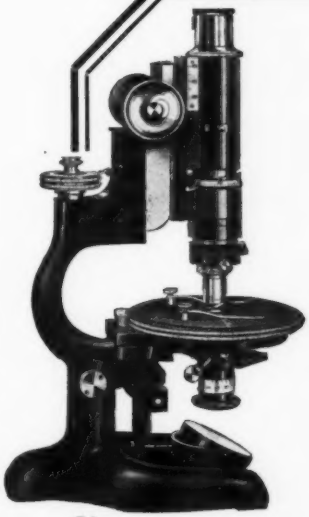
xlii + about 546 pages, 6 by 9 inches, 169 half-tones and 24 sections and maps.

Formations from Archeozoic to Recent are named, described, correlated, and mapped. All important mineral deposits are discussed. Special reference is made to producing oil fields. Their location, general structure, depth to and character of producing sands, gravity of oil, and amount of production are given. The book is designed to be of especial assistance to petroleum geologists and oil operators as well as to those interested in the more academic side of stratigraphy, structure, and paleontology. Contains a bibliography of all important geologic works on Venezuela and Trinidad. Bound in cloth; gold title.

PRICE, POSTPAID, $7.50

Order from J. P. MACGOWAN

BOX 1,007 Fort Worth, Texas



A Microscope for Every Petrographer

Three models of B & L Petrographical Microscopes make available a microscope suited to the requirements of every petrographer. The complete line consists of—

The LA—for Students
The LCH—for Laboratory Workers
The LD—Completely equipped for Research

Each instrument in this series is fully equipped to take care of every need in the particular field to which it is adapted.

Write for literature describing

BAUSCH & LOMB
Petrographical Microscopes

BAUSCH & LOMB OPTICAL CO.
669 St. Paul St., Rochester, N. Y.

A Subscriber Writes:

"I wish to inform you that I find your journal full of most valuable information from start to finish and I am only sorry that I did not subscribe sooner."

You, too, will find much information of interest and value in

The OIL WEEKLY

If you read the "Office copy," why not have a copy sent to your home where you can read it at your leisure? The cost is only $1.00 a year. Use the attached order blank—NOW.

The OIL WEEKLY

P. O. BOX 1307 HOUSTON, TEXAS

Enter my name for one year's subscription to The OIL WEEKLY, for which you will find enclosed check for $1, as payment in full.

Name.....

Street and No.....

City and State.....

I am with The.....Company

and my position is.....

(BE SURE TO STATE COMPANY AND POSITION, otherwise it will be necessary for us to hold up entering your subscription until we can get this information from you.)

PETTY GEOPHYSICAL ENGINEERING COMPANY, INC.
706 Travis Building — San Antonio, Texas

Experienced seismograph crews available for consulting work. Only latest equipment and methods used.

Geophysical departments established for oil companies. Complete seismograph, radio and blasting equipment carried in stock, sold only in connection with establishing departments.

THE KELLY MAP COMPANY

OIL FIELD MAPS — BASE MAPS FOR GEOLOGICAL COMPILATIONS AND REPORTS — BLUE PRINTING

Our Service Covers---Oklahoma, Texas, Kansas, New Mexico, Arkansas, Louisiana, Colorado, Wyoming, and Montana

319 South Boston Ave. — TULSA, OKLAHOMA — P. O. Box 1773

OIL FIELD MAPS

HEYDRICK MAPPING COMPANY
WICHITA FALLS, TEXAS

FIELD STATIONERY COMPANY
Complete Office Outfitters
612 South Main — TULSA — Phone 3-0161

TRIANGLE BLUE PRINT & SUPPLY COMPANY

COMMERCIAL BLUE PRINTING
PHOTOSTATING & OIL FIELD MAPS

ENGINEERING, DRAFTING & ARTIST SUPPLIES

Mid-Continent Representative for Spencer, Bausch & Lomb, and Leitz Microscopes and Accessories

12 West Fourth St. — Phone 9088 — Tulsa, Okla.

THE SOUTHWEST ELEVATION CO.
209 PETROLEUM BLDG. — FORT WORTH, TEXAS

WELL ELEVATION SERVICE - - - - - ALWAYS RELIABLE

ENDORSED AND SUBSCRIBED TO BY MOST MAJOR COMPANIES

Service Covers All of Northwest Half of Texas

Be sure to mention the BULLETIN when writing to advertisers.

NATIONAL PETROLEUM ENGINEERING COMPANY
Engineers and Geologists
TULSA, OKLAHOMA

APPRAISALS
REPORTS - COMMERCIAL and TAX

SURVEYS
ESTIMATES OF OIL RESERVES

OKLAHOMA'S LARGEST BANK and TRUST COMPANY

EXCHANGE BANKS OF TULSA
The Exchange National Bank — Exchange Trust Company
"The Oil Banks of America"

Capital, Surplus and Profits Exceed $5,000,000
Resources Exceed $70,000,000

Latest developments in geological and geophysical operations and in matters of interest to geologists generally are covered best and most comprehensively in

Published Weekly

The OIL and GAS JOURNAL
PRODUCING REFINING ENGINEERING MARKETING
TULSA, OKLAHOMA

Subscription $6.00 a Year

Verlag von Gebrüder Borntraeger in Berlin W 35 (Deutschland)

Allgemeine Petrographie der „Ölschiefer" und ihrer Verwandten mit Ausblicken auf die Erdölentstehung (Petrographie und Sapropelite) von Dr. Robert Potonié. Mit 27 Abbildungen. (IV u. 173 S.) 1928 Gebunden, 14 Marks

Einführung In die allgemeine Kohlenpetrographie von Privatdozent Dr. Robert Potonié. Mit 80 Textabb. (X u. 285 S.) 1924 Gebunden, 14 Marks

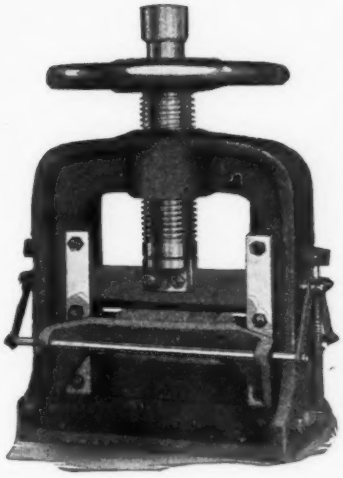
Die Entstehung der Steinkohle und der Kaustobiolithe überhaupt wie des Torfs, der Braunkole, des Petroleums usw. von Geh. Bergrat Professor Dr. H. Potonié. *Sechste durchgesehene Auflage* von Professor Dr. W. Gothan. Mit 75 Abbildungen. (VIII u. 233 S.) 1920 Gebunden, 15 M.

Der Bewegungsmechanismus der Erde von Dr. R. Staub. Mit einer Erdkarte und 44 Textfiguren. (VIII u. 269 S.) Gebunden, 20.50 M.

Sammlung naturwissenschaftlicher Praktika
Band 14: **Kohlenpetrographisches Praktikum** von Dr. Erich Stach, Geologen an der Preussischen Geologischen Landesanstalt. Mit 64 Textfiguren. (IV u. 204 S.) 1928 Gebunden, 10.80 M.

Ausfürliche Verlagsverzeichnisse kostenfrei
(Detailed list of publications will be sent free)

Be sure to mention the BULLETIN when writing to advertisers.



Longyear Core Splitter

Duplicate core samples for special examination and analysis are often necessary or desirable. Upon such an occasion, the Longyear Core Splitter will exactly serve your purpose. With this simple Longyear device, rock cores may be halved or quartered lengthwise so that a complete longitudinal section of the cores may be retained for permanent filing and reference, with duplicate core samples also available.

The Longyear Core Splitter is made in three sizes: for cores 15/16 in. to 2 in., from 1 3/8 in. to 3 1/2 in., and from 4 in. to 6 in., the latter operated by hydraulic pressure. We shall be glad to furnish information as to prices and weights upon request.

Longyear Core Splitters and Diamond Drill Supplies are carried in stock at Ponca City, Oklahoma, and Marquette, Mich.

E. J. Longyear Company
Minneapolis, Minnesota, U.S.A.

PATRICK CARBON
for Diamond Core Drilling

Drilling for Production

THE recent successful applications of the Diamond Core Drill to production drilling—although a radical development of drilling practice—have vastly enlarged the field of usefulness of this efficient equipment.

The certainty, speed and economy of the Diamond Core Drill equipped with Patrick Carbon have brought it into world-wide service for exploration drilling. The full, accurate core it can yield—its greater speed—its capacity to penetrate any structure to greater depths—the possibility of holding extraordinary pressures under control—the economies resulting from fewer round trips in and out—these and other advantages of the Diamond Core Drill are what have merited its wide acceptance. Now, with the drilling of larger holes than were heretofore regarded as practicable, its use in production drilling demonstrates a new service it can render, economically and efficiently.

The Patrick Organization, although engaged exclusively in the distribution of Carbon (Black Diamonds), has been actively concerned for many years in assisting in the development of the Diamond Core Drill. By maintaining intimate contacts with actual drilling operations all over the world, this organization has been able to build up an exceedingly valuable experience in drilling that is freely available for the assistance of drillers everywhere. It is from this practical experience, applied to the grading, breaking, shaping and selection of Carbon for drillers' specific needs, that Patrick Carbon derives its drilling value. This is what is back of the Reliability that has made Patrick Carbon the standard wherever Quality Carbon is used.

Drillers and others interested are invited to communicate without obligation with the Patrick Research Department for further information on Diamond Core Drilling. Several interesting booklets, including "Diamond Core Drilling in Oil Field Practice," are available free upon request.

R. S. PATRICK
Duluth, Minnesota, U.S.A.
Cable Address, "Exploring" Duluth

2½ square miles contoured in 2 days

by two men using Paulin Altimeters

THIS aerial photograph, made at 12,000 feet altitude by The Texas Company aerial surveyors, using the Paulin System Level Flight Indicator, shows approximately 2½ square miles of land under survey. With the print as a basis, two men with Paulin System Altimeters contoured this tract in two days. The contours are at 50-foot intervals. You too can cut down the time and labor cost on your preliminary surveys by using this highly sensitive and extremely accurate instrument. Mail the coupon below for a free copy of the "Paulin System Altimetry Manual." It will interest all engineers. Address the coupon to our nearest office.

The AMERICAN PAULIN SYSTEM, Inc.

General Offices and Manufacturing Laboratories

1220 MAPLE AVE., LOS ANGELES, CAL.

Eastern Office

55 WEST 42ND ST., NEW YORK CITY

Dealers in principal cities of North and South America, Japan, China and all U. S. Possessions

PG-9

The American Paulin System, Inc.,
1220 Maple Ave., Los Angeles, Cal.
55 West 42nd St. New York City

Please send me by return mail a free copy of the "Paulin System Altimetry Manual for Engineers."

Name .....

Address .....

Instrument Dealer .....

A Part of every dollar you spend today for Hughes tools is devoted to a never-ceasing effort on the part of the Hughes Tool Company to develop tools of even more effectiveness to meet tomorrow's requirements of the industry

Hughes Tools Sold by Supply Stores Everywhere

HUGHES TOOL COMPANY

Main Office and Plant

HOUSTON
TEXAS

Service Plants
Los Angeles, Calif.
Oklahoma City, Okla.

Export Office
Woolworth Bldg.
New York City